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Veeco's New TurboDisc EPIK700 GaN MOCVD System

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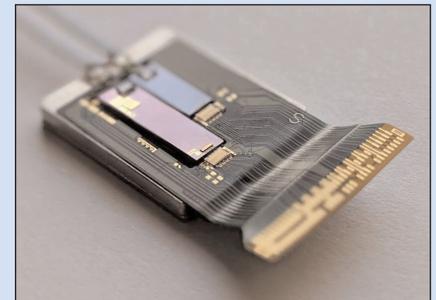
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**p44** StratEdge has moved its global headquarters into new facilities near San Diego.



**p56** Osram Opto Semiconductors is cutting 300 of the 2800 jobs in Regensburg by the end of September.



**p69** Rockley Photonics has completed its fully integrated silicon photonics platform running in a large-scale foundry environment.



Cover: IQE says that, within the first year of the compound semiconductor wafer foundry in Newport, South Wales, 32 technicians and engineers have begun work, with a further 10 vacancies in the process of being filled.  
**p32**

## Counteracting China slowdown

The December 2018 quarter saw a rash of financial results impacted by slowdowns in the China market.

RFIC maker Qorvo reported revenue of \$832m (down 1.6% year-on-year), below the guided \$880–900m (see page 8). In particular, Mobile Products revenue was down 6% due to weaker flagship phone volumes and a softer China domestic market (30% of mobile revenue, even excluding Huawei, one of Qorvo's largest end-customers after Apple). "The outlook for smartphones is being affected by a range of factors, including trade tensions," said president & CEO Bob Bruggeworth.

The firm has hence begun a phased closure of its SAW filter fab in Florida and a transfer of production to Greensboro, NC (by end 2019). Also, it is idling its fab in Farmers Branch, Texas, rather than moving it from start-up to production. BAW filter resources will be consolidated in Richardson, Texas, while preserving the flexibility to ramp up Farmers Branch in future.

For the March quarter, Qorvo expects a 25% sequential drop in Mobile Products revenue, with China down again (to below 30% of mobile revenue).

Fellow RFIC maker Skyworks reported revenue of \$972m, down 7.6% year-on-year (below the \$1–1.02bn original guidance) — see page 10. Unit declines across its Mobile business were driven by weak end-customer demand in China (20% of total revenue). For the March quarter, Skyworks expects revenue to fall to \$800–820m (including a further decline in China).

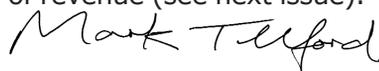
For Veeco, its LED Lighting, Display & Compound Semiconductor segment plunged from 46% of total revenue in Q3 to 14% in Q4/2018 (see page 38). "The commodity portion of the LED business, which includes the sale of our MOCVD systems to the China LED market, has been under pricing pressure and is becoming a smaller portion of our business," notes CEO Bill Miller. Most of this segment's revenue was hence in 'Compound Semiconductors', including MOCVD systems for specialty LEDs, automotive, photonics and power electronics applications. China has plunged from 31% to 9% of total revenue (having been 47% in Q2). LED Lighting, Display and Compound Semiconductor orders remained just 12% of bookings due to the reduced levels of commodity blue LED business (especially from China). Veeco is hence focusing on transitioning business from commodity blue LED MOCVD markets to Front-End Semiconductors and Compound Semiconductors.

Substrate maker AXT's revenue was just \$22.2m (well below its original guidance of \$26.5–27.5m) — see page 34. "This shortfall was a combination of trade tension, weakness in the LED market (particularly in China and for applications such as automotive)," says CEO Morris Young. Of total revenue, 69% came from Asia Pacific (down from 72% last quarter).

Osram was impacted by unfavorable developments in the automotive industry, especially in China, as well as the mobile devices sector (page 56). In particular, the Opto Semiconductors division saw revenue fall 17% year-on-year, prompting it to cut 300 of 2800 jobs in Regensburg by October.

Factors affecting these firms are not just weak demand in commoditized markets such as blue LED manufacturing in China but the burgeoning opportunities in 'specialty' markets. This is exemplified by the Wolfspeed Power & RF devices and silicon carbide materials business growing by 50% year-on-year, rising from 19% to 33% of LED maker Cree's total revenue (page 54). Meanwhile, MOCVD system maker Aixtron has reported full-year revenue growth of 40%, with laser, red-orange-yellow & specialty LED and power electronics applications rising to 90% of revenue (see next issue).

**Mark Telford, Editor**



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- event calendar and event previews;
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## Inaugural 'GaN Con — Power GaN' technology day organized by Yole, EPC and SEMI

Eight years have passed since the first commercialized power GaN device. People in the power electronics industry are becoming increasingly familiar with the names of start-ups that are actively promoting gallium nitride technology. In addition to the power electronics leaders Infineon Technologies and ON Semiconductor, Efficient Power Conversion Corp (EPC), GaN Systems, Transphorm and Navitas are also involved in the development of GaN technology. Moreover, unsurprisingly, the list of GaN start-up players has been growing over the years, with Exagan, GaNPower International and Tagore Technology also offering power GaN products.

In the context of this dynamic ecosystem, market analyst firm Yole Développement and its partners EPC and trade organization SEMI organized 'TechDay: GaN Con — Power GaN: from promises to possible market explosion' on 21 February in Milpitas, CA, USA, a combination of conference presentations by leading power GaN companies, debates and networking.

Most power GaN start-ups choose the foundry model, mostly using TSMC, Episil or X-Fab as their preferred partner. Meanwhile, other foundries may offer this service if

the market takes off. The foundry model affords fabless or fab-lite start-ups the possibility of ramping up quickly if the market suddenly takes off, while existing integrated device manufacturers (IDM) can benefit from previous acquired equipment and knowledge for GaN manufacturing.

"It is fascinating to see that, along with these start-up players, companies with very different profiles are competing in the same playground: industrial giants like Infineon Technologies, ON Semiconductor, STMicroelectronics, Panasonic and Texas Instruments," comments Yole technology & market analyst Ana Villamor Ph.D.

The report 'Power GaN: Epitaxy, Devices, Applications, and Technology Trends' by Yole's Power & Wireless team highlighted several new factors in 2018. Power electronics leader Infineon Technologies announced it would begin volume production of CoolGaN 400V and 600V enhancement-mode (E-mode) high-electron-mobility transistor (HEMT) products at the end of 2018. "This announcement is a strong sign for the power GaN industry," says Yole technology & market analyst Ezgi Dogmus Ph.D.

"Because of its leadership, Infineon Technologies has already many

customers for silicon products that could shift to GaN solutions in the near future, if their requirements are satisfied." GaN adoption by the biggest player gives confidence for future market growth.

In parallel, STMicroelectronics and CEA-Leti announced their cooperation in developing gallium nitride on silicon (GaN-on-Si) technologies for both diodes and transistors on Leti's 200mm R&D line. Both partners expect to have validated engineering samples in 2019. Also, STMicroelectronics will create a fully qualified manufacturing line, including GaN-on-Si heteroepitaxy, for initial production running in its front-end wafer fab in Tours, France, by 2020.

Promisingly, new commercial products arrived during the last year, and more will come in 2019. The main ones released were power supply products for high-end or high-volume consumer applications. At the moment, each segment is being targeted by companies with different profiles: integrated solutions for consumer applications and discrete solutions for high-power/high-end power supplies, notes Yole, which elaborates further in its 'Power GaN' report.

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# Qorvo's 5G infrastructure revenue growth offsets weak mobile market in China

## Florida SAW fab to close; Farmers Branch BAW fab start-up delayed

For fiscal third-quarter 2019 (to 29 December 2018), Qorvo Inc of Greensboro, NC, USA has reported revenue of \$832.3m (down 5.9% on last quarter's record \$884.4m and 1.6% on \$845.7m a year ago). This is below the guided \$880–900m but \$12m above the mid-point of the updated guidance range of \$800–840m given on 13 November.

Qorvo had two 10%-or-more customers (one a large Chinese OEM).

Mobile Products (MP) revenue was \$602m, down 9.7% on \$667m last quarter (and 6% on \$642m a year ago) due to weaker flagship phone volumes and a softer China domestic market (about 30% of mobile revenue, excluding Huawei). Nevertheless: "we extended the commercial adoption of our bulk acoustic wave (BAW)-based solutions to include additional marquee smartphone customers," says president & CEO Bob Bruggeworth. Qorvo has begun shipments to a leading South Korean firm (for its upcoming marquee smartphone) of a highly integrated mid/high-band PAD (power amplifier duplexer) and ultra-high band (UHB) 3.5GHz front-end module (FEM) featuring Qorvo's BAW-based multiplexer technology. It has also expanded support of Huawei by supplying the mid/high-band PAD, low-band PAD, antenna tuning and an envelope-tracking PMIC for its Mate 20 smartphone. "Our BAW-based wins are complemented by other high-value Qorvo components, including our industry-leading envelope trackers and antenna control solutions," adds Bruggeworth.

Infrastructure & Defense Products (IDP) revenue was a record \$230m, up 5.5% on \$218m last quarter and 13.5% on \$202.7m a year ago (making an 11th consecutive quarter of double-digit year-on-year growth). "IDP is experiencing especially strong growth in infrastructure as

carriers pick up the pace of their 5G investments," notes chief financial officer Mark Murphy. Qorvo significantly increased shipments of 5G massive MIMO infrastructure solutions to multiple OEMs and secured additional design wins across all anticipated 5G frequency bands, from sub-6GHz to millimeter wave.

In Defense, Qorvo won a multi-year production contract supporting a large defense aerospace program and is shipping production volumes of high-frequency BAW filters, significantly extending the frequency range of its BAW technology.

"Qorvo offers base-station OEMs a unique combination of GaN technology and decades of experience in phased arrays for defense, which is translating into significant massive MIMO business," says Bruggeworth. "The economics of this business are compelling, as a typical MIMO implementation has four times more channels (8–12 times more RF content than a typical macro base station). There is approximately \$1200 of RF content in each of these base stations."

On a non-GAAP basis, gross margin is up from 47.7% last quarter to 49.5% (below the original guidance of 50%, but matching the revised guidance, aided by mix improvements in factory productivity.

Due to tighter spend control and lower employee-related costs (including incentive compensation), operating expenses were cut from \$168.3m last quarter to a fiscal-year low of \$150.5m (back to the \$150.8m of a year ago, and below both the revised guidance of \$161m and original guidance of \$165m).

Net income has risen further, from \$220.2m (\$1.69 per diluted share) and \$224.9m (\$1.75 per diluted share) last quarter to a record \$234.1m (\$1.85 per diluted share, below the guidance of \$1.95 but above the revised guidance of \$1.70).

"Despite substantial headwinds from a weaker-than-expected mobile market and ongoing macro-economic instability, Qorvo delivered its best quarter ever on earnings and free cash flow," says Murphy.

Operating cash flow was \$333m (up from \$270.1m last quarter). Capital expenditure (CapEx) was \$72m (up from a low of \$45.5m). Free cash flow was hence \$261.3m (up from a record \$224.6m). "Our focus on portfolio management and operating discipline are yielding stronger earnings and free cash flow," says Murphy.

During the quarter, Qorvo repurchased a record \$152m of its stock (almost doubling from last quarter). This makes the last three quarters three of the four largest repurchase periods outside the firm's accelerated share repurchase (ASR) program of 2016. Cash and cash equivalents hence rose from \$558m to \$649.7m.

The performance is "especially noteworthy, given that the smartphone market weakened considerably after we entered the quarter," states Bruggeworth. "The outlook for smartphones is being affected by a range of factors, including trade tensions, and other macro-economic headwinds, longer replacement cycles, and what may be a pause in demand ahead of 5G smartphone launches," he adds.

"During the quarter, we initiated actions to improve our manufacturing cost structure in light of multiple factors affecting our near-term outlook for mobile products volumes."

● Due to market and fab-specific factors, Qorvo began a phased closure of its surface acoustic wave (SAW) fab in Apopka, Florida and a transfer of production to Greensboro (to complete by calendar year-end). The firm will incur ongoing period costs in Florida of \$6–8m per quarter (for fiscal 2020 through December) as it completes end-of-life product

builds and other final production activities. Qorvo expects to gain production efficiencies for both SAW and GaAs devices from increased loadings at the Greensboro fab. "Our proven SAW technology is an important capability for Qorvo going forward, especially for some of our most complex solutions utilizing both SAW and BAW filters," says Murphy. The Florida engineering teams doing advanced filter design and product and process technology development will not be directly affected. "In fact, we are increasing investments in support of development activities," he adds.

● Qorvo is idling its fab in Farmers Branch, Texas, rather than moving it from start-up to production. BAW resources and production will be consolidated in the near term at the firm's fab in Richardson, Texas, while preserving the flexibility to scale production in Farmers Branch to meet expected future growth. Ongoing period costs will be about \$5m in the March quarter, and drop to \$3m per quarter until the fab starts production (in early calendar 2020). "Given the proximity of the Farmers Branch fab to our Richardson fab and the favorable start up yields we achieved in Farmers Branch, we believe Farmers Branch will play a critical future role by allowing us to scale our BAW production efficiently in response to demand," says Murphy.

As well as \$18m of fiscal Q3/2019 Florida fab asset impairment charges and accelerated depreciation, over the next fourth quarters Qorvo expects to record \$100m of further charges for accelerated depreciation in Florida, plus staff termination and other exit costs related to Florida, Texas and other locations impacted by the restructuring.

For fiscal fourth-quarter 2019 (to end-March), Qorvo expects revenue to fall to \$660–680m. While continuing to see double-digit year-on-year growth, IDP revenue will be roughly flat sequentially (sustained by continued strength in 5G infrastructure market demand). However, there will be a 25% sequential drop in Mobile Products

revenue, with the firm's largest customer down and China down again more than expected (to below 30% of mobile revenue), plus worse-than-normal seasonal falls in the broader smartphone market. This will be offset partially by regaining market share at Huawei plus content gains with leading Korean smartphone maker Samsung. Qorvo should hence have three 10%-or-more customers for the first time since the March 2016 quarter. "Lower mobile volumes will cause us to fall short of our original target for the second half of fiscal 2019," warns Murphy.

Gross margin should fall to 47%, reflecting the lower revenue, lower utilization (including the impact of the Farmers Branch and Florida period costs of \$13m) and less favorable product mix, partially offset by improved segment mix.

OpEx will rise to \$160m due to seasonal payroll effects and higher investment to support IDP growth.

Diluted earnings per share should fall to \$1.05. However, operating cash flow will remain strong, helped by working capital management. CapEx will fall as Qorvo focuses on IDP growth opportunities and priority Mobile development programs (ending the fiscal year at \$240m). Free cash flow should exceed \$600m for fiscal 2019 (up on 2018's \$583m).

"Despite the near-term headwinds in mobile, I am pleased with our operational performance and excited about our position in the markets we serve, including 5G, WiFi 6 [802.11ax], IoT and defense," says Bruggeworth.

"We're supporting robust 5G design activity at many mobile customers, primarily for ultra-high-band sub-6GHz applications. We expect 5G smartphones to launch this year, with rapid growth expected in calendar 2020," he adds. "We're also continuing to see interest in our millimetre-wave solutions for handsets, and we expect phones to be available as early as 2020. Whether the devices are fixed, nomadic or mobile, our deep experience in millimeter wave

in the defense and infrastructure markets positions Qorvo to play a key role in delivering these solutions into the commercial markets."

Also, Qorvo has secured a design win to supply both its 2.4 and 5GHz WiFi FEMs for NETGEAR's Orbi Voice tri-band distributed WiFi systems. "We're expanding our footprint in the connected home by helping to deliver broader coverage and higher data rates to consumers," says Bruggeworth. "Over time, we see WiFi nodes proliferating in the smart home from 10 today to more than a 100, and we envision multi-protocol pods in every room incorporating multiple low-power radios."

In IoT, Qorvo has expanded into new markets, including shipments of multi-protocol Zigbee/BLE SoCs for electronic shelf labeling.

"In automotive, we're broadly engaged with OEMs and tier-1 suppliers, and we've expanded our product offering to address multiple protocols, including satellite, WiFi, LTE, 5G and V2X," says Bruggeworth. "As increasingly complex coexistence requirements evolve in automotive applications, we see new opportunities for our BAW filters."

In Defense, Qorvo has won a four-year contract with the US Air Force to develop new modeling and simulation tools to accelerate GaN designs for mission-critical applications.

"Steps to right size our manufacturing footprint, along with targeted reductions in OpEx and redirecting certain R&D resources, are together designed to allow us to pursue growth opportunities for IDP, sharpen our focus in mobile products on the highest-value most complex opportunities, and achieve earnings and free cash flow growth in fiscal 2020," says Murphy.

"Investments in 5G are accelerating, the roll out of WiFi 6 is coming soon and IoT continues to proliferate," says Bruggeworth. "The robust demand we're enjoying for infrastructure solutions supports the outlook that 5G capabilities are coming sooner than our industry had originally expected."

[www.qorvo.com](http://www.qorvo.com)

# Skyworks quarterly revenue down 7.6% year-on-year to \$972m

## Mobile revenue from China to fall further; Broad Markets to rebound

For fiscal first-quarter 2019 (to 28 December 2018), Skyworks Solutions Inc of Woburn, MA, USA (which manufactures analog and mixed-signal semiconductors) has reported revenue of \$972m, down 3.6% on the record \$1008m last quarter and down 7.6% on \$1051.9m a year ago (and below the \$1-1.02bn original guidance given on 8 November).

The firm's largest customer comprised more than 50% of total revenue (as usual for a December quarter).

By market sector, Mobile (Integrated Mobile Systems and Power Amplifiers) comprised 73% of revenue and Broad Markets 27%.

"Momentum in our high-growth Broad Market business allowed us to partially offset unit declines across our Mobile business," says senior VP & chief financial officer Kris Sennesael. "That was mostly driven by weak end-customer demand in China [20% of total revenue]," he adds. "Revenue from Broad Markets continued to outperform... We have double-digit revenue growth compared to the first quarter of last year, demonstrating continued diversification across multiple end-markets, customers and applications."

On a non-GAAP basis, gross margin was 51%, down from 51.2% last quarter and 51.4% a year ago.

Operating expenses (OpEx) have risen from \$136m (13.5% of revenue) last quarter to \$139m (14% of revenue), although this was slightly below the expected \$140m.

Operating income has fallen further, from \$414m (operating margin of 39.4%) a year ago and \$379.6m (37.6% margin) last quarter to \$356.4m (36.7% margin).

Likewise, net income has fallen further, from \$371.5m (\$2.00 per diluted share) a year ago and \$349.7m (\$1.94 per diluted share)

last quarter to \$324.6m (\$1.83 per diluted share, below November's original guidance of \$1.91).

"Despite macro weakness across our global Mobile business, Skyworks delivered solid financial results driven by content gains, our expanding footprint and Broad Markets to continued execution of our innovator product strategy, and the strength of our business model," says president & CEO Liam Griffin. "We are continuing to deliver high levels of profitability with consistently strong cash flow," he adds.

Cash flow from operations was a record \$549m. Capital expenditure (CapEx) was \$129m. Free cash flow margin was hence strong (representing free cash flow margin of about 43%).

During the quarter, Skyworks paid \$67m in dividends, and repurchased a record 4 million shares of common stock for a total of \$284m.

Overall, cash, cash equivalents and marketable securities hence rose by \$51.6m from \$1.050bn to \$1.102bn. The firm has no debt.

"These results highlight our success as we continue to increase our product reach across a growing set of end markets, applications and customers," says Griffin.

During the quarter, Skyworks expanded its design-win pipeline in several emerging high-growth categories. "Our solutions are now enabling the newest Wi-Fi standards along with the latest advances in MIMO base stations and across mobile payment platforms. For example, our Wi-Fi 6 products are now powering Net-Gear routers, Charter Communications' Home Gateways and Ruckus' Indoor Access Points, to name just a few," says Griffin. "We also partnered with Square, a market-leading mobile payment platform, powering their latest long-range retail systems. We supported next-

generation high-fidelity smart audio solutions for Bose and Sonos enabled by Alexa voice controls. In addition, we've ramped advanced wireless engines supporting Phillips end-to-end street-light management platforms," he adds.

"Across the infrastructure space, we've secured a number of massive MIMO wins with leading base-station providers [in Europe] as they prepare for the ramp to 5G. Across automotive, we supported next-generation telematics [remote access] solutions for leading German and Korean manufacturers," continues Griffin.

"Looking ahead, we are leveraging our demonstrated technology leadership, trusted customer partnerships and innovative Sky5 portfolio to capitalize on compelling 5G, IoT and automotive opportunities," says Griffin.

"In the March quarter, we expect diversification and momentum in our high-growth Broad Markets business to partially offset unit declines in mobile," says Sennesael.

For fiscal second-quarter 2019, Skyworks expects revenue to fall \$800-820m (with a further minor sequential decline from China offsetting continued growth in Broad Markets). Despite the decline from \$913.4m a year previously, gross margin should be level year-on-year, at 50.5-51%. "In light of the market backdrop, we will continue to drive operational efficiencies and prudently manage our operating expenses down to approximately \$135m," says Sennesael. "I feel good about our ability to further expand the gross margin towards our target model of 53%," adds Griffin. Diluted earnings per share should fall to \$1.43.

Skyworks' board of directors has declared a cash dividend of \$0.38 per share of common stock, payable on 19 March to stockholders

of record at the close of business on 26 February.

The board has also approved a new \$2bn stock repurchase program (superseding the \$1bn share buyback program instituted in January 2018, of 88% was executed, leaving \$129m). "This new buyback plan reflects our confidence in Skyworks' business model and our ability to consistently produce strong free cash flow, allowing us to leverage share repurchases and dividends to generate higher shareholder returns," notes Sennesael. "Our strong balance sheet and cash position provide important competitive advantages, allowing us to make the strategic investments in R&D while funding the capital requirements for 5G, as a complexity of our solutions intensifies."

"We have strategically positioned Skyworks to outperform, as we seize upon a complex set of new opportunities in both Mobile and Broad Markets. For example, the shift of 5G is a tremendous catalyst representing an entirely new connected ecosystem, one where Skyworks will play a leadership role," says Griffin. "At a higher level, 5G will be transformational, requiring step-function increases in analog performance, advanced filtering and power efficiency. With decades of experience spanning successors technology generations, Skyworks is well positioned to capitalize with strategic partnerships across all smartphone and IoT customers, differentiated systems solutions, enabling unmatched levels of integration and performance, focused

investments to expand our product portfolio, IP and scale," he adds.

"Looking ahead, 5G technology will fuel a broad array of markets and applications, ranging from industrial IoT, automotive, machine to machine, healthcare, smart cities as well as artificial intelligence," says Griffin. "Capitalizing on the advances of our mobile solutions, the launch of strategic product categories and the diversified strength of broad markets, we remain confident in our ability to outperform," he adds. "We are squarely focused on operational excellence while continuing to invest strategically across innovative technologies and products, establishing a firm foundation for future growth."

[www.skyworksinc.com](http://www.skyworksinc.com)

## Skyworks announces new \$2bn stock repurchase program

Skyworks' board of directors has authorized the repurchase of up to \$2bn of its common stock from time to time prior to 30 January 2021 (on the open market or in privately negotiated transactions) in compliance with applicable securities laws and other legal requirements.

The newly authorized stock repurchase program replaces in its

entirety the \$1bn stock repurchase program that was approved by the board on 31 January 2018, and had about \$129m of repurchase authority remaining.

The timing and amount of any shares repurchased under the new program will be determined by the management based on its evaluation of market conditions and other factors. The repurchase pro-

gram may be suspended or discontinued at any time.

Any repurchased shares will be available for use in connection with the firm's stock plans and for other corporate purposes.

Skyworks expects to fund the repurchase program using its working capital. As of 28 December, the firm had cash and marketable securities of \$1.1bn.

## MediaTek using Skyworks' Sky5 suite for sub-6GHz 5G reference platform

Skyworks' Sky5 suite is being used by Taiwanese fabless semiconductor firm MediaTek Inc, a provider of system-on-chip (SoC) platforms for mobile device, home entertainment, connectivity and IoT products, for its new 5G reference platforms.

Specifically, Skyworks' complete 5G front-end architecture is being combined with MediaTek's 5G baseband chipset to deliver highly integrated solutions targeting open-market mobile products. The comprehensive sub-6GHz system enables high-speed network functionality with optimized efficiency and near-zero

latency for emerging applications.

"Given Skyworks' RF expertise and proven performance over successive wireless standards, they are a perfect complement to MediaTek for bringing breakthrough solutions to the market," comments TL Lee, general manager of MediaTek's wireless communications business unit. "Our strategic relationship has spanned from 2G to 4G/LTE Advanced and now 5G. Together we have created a solid foundation to address the complexities of 5G and deliver a powerful ecosystem," he adds.

"With our Sky5 suite, we are enhancing performance in a fully integrated system, facilitating seamless implementations and faster end-user equipment rollouts as demand for greater speeds and efficiency surges," says Joel King, senior VP & general manager of Mobile Solutions at Skyworks.

All Sky5 solutions support new 5G NR waveforms and spectrum in addition to enhanced carrier aggregation and 4G/5G dual connectivity, while delivering high levels of integration and performance.

[www.mediatek.com](http://www.mediatek.com)

# Tyndall and Arralis sign €400,000 R&D deal to develop high-volume manufacturing process for scaling mmWave integration and packaging technologies

## Enterprise Ireland's Innovation Partnership program to support development of Ka- and W-band MMICs

Arralis Ltd of Limerick, Ireland — which has a design center in Belfast and manufactures RF, microwave and millimetre-wave devices, modules and antennas up to and beyond 110GHz (the W-band) for aerospace/satellite and security markets — has entered into a €400,000 R&D agreement with Tyndall National Institute (a research flagship of University College Cork in Ireland) to develop next-generation mmWave fabrication technology for applications such as autonomous vehicles (AVs), satellite communications, 5G and radar imaging.

The project “combines Tyndall’s micro-fabrication expertise in thick-film electrochemical simulation, processing, integration and testing with the design capabilities of Arralis for the rapidly developing mmWave device market,” says Tyndall’s senior staff scientist Dr James Rohan.

Supported by Enterprise Ireland through the Innovation Partnership program, the development of new monolithic microwave integrated circuits (MMICs) is regarded as vital, given the growth of data-centric traffic, increased demands on existing communications networks and future Internet of Things (IoT) application requirements including

autonomous vehicles and satellite communications.

“Our data-hungry society demands constant, uninterrupted access to more and more information, and this demand will only increase in the future,” says Marie Bourke, Arralis’ business process manager & technical program manager. “New cost-effective, high-volume and geometry-scaled mmWave manufacturing is needed to meet future IoT demands,” she adds. “The partnership of two leaders in this area, Arralis and Tyndall, will enable us to take a step closer to global interconnectivity through new integrated mmWave technologies.”

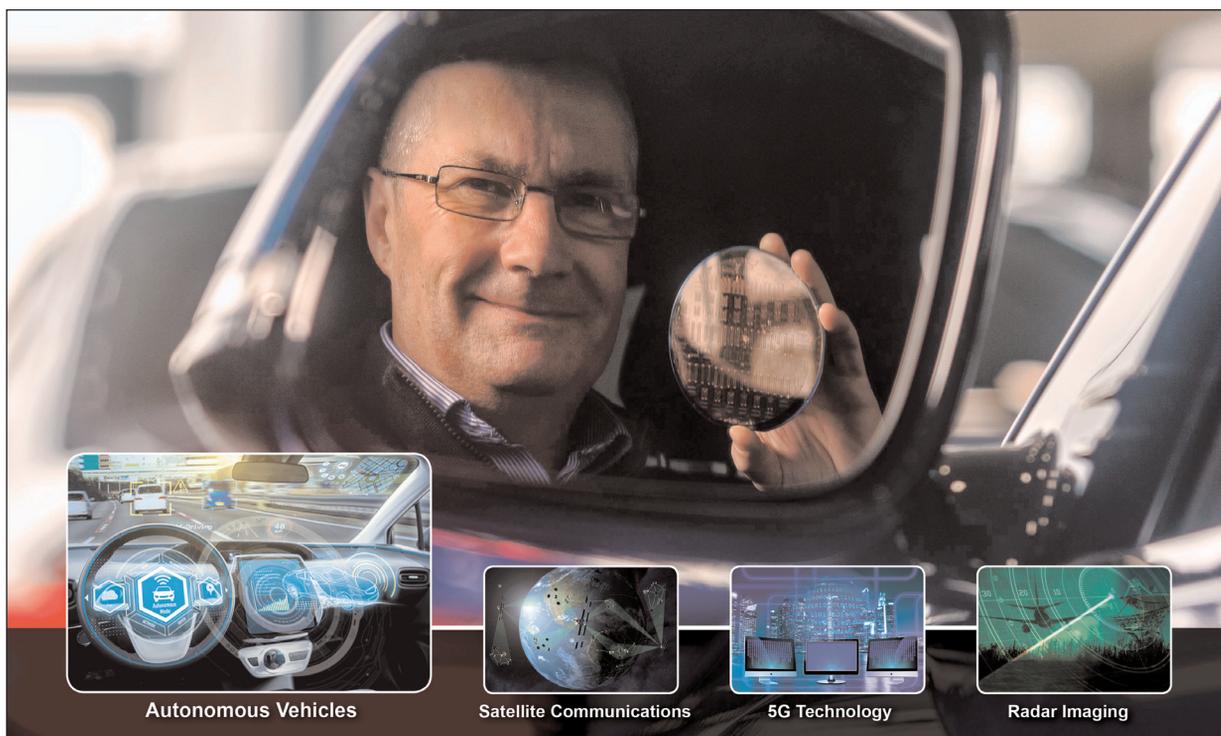
As autonomous vehicles require unimpeded data access to connected vehicles, Ka- and W-band wireless communications are essential. Ka-band supports high data rates, device connectivity, data collection and traffic handling capacity at lower latency than

existing technologies, leading to the expectation that 5G will be up to 60 times faster than 4G networks.

“The combination of world-class research at Tyndall, and market leading manufacturing expertise of Arralis ensure that this will be a highly effective collaboration as well as a timely one, given the proposed testing of autonomous vehicles on Ireland’s road infrastructure in the coming years,” reckons Carlo Webster, senior strategic business development executive at Tyndall. “Tomorrow’s cars will be computers on wheels and will require Ka-band mmWave technology to simplify and support the communication protocol between the car and its environment. Arralis is a leader in the field of mmWave design and, together with Tyndall, we will accelerate innovation in this and other areas.”

[www.tyndall.ie](http://www.tyndall.ie)

[www.arralis.com](http://www.arralis.com)



## GlobalFoundries' mobile-optimized 8SW RF SOI technology surpasses billion-dollar design-win threshold

GlobalFoundries (GF) of Santa Clara, CA, USA (one of the world's largest semiconductor foundries, with operations in Singapore, Germany and the USA) says that its mobile-optimized 8SW radio-frequency silicon-on-insulator (RF SOI) technology platform has delivered more than a billion dollars of client design-win revenue since its launch in September 2017. With yields and performance that are claimed to be exceeding client expectations, 8SW is enabling designers to develop solutions that offer extremely fast downloads, higher-quality connections and reliable data connectivity for 4G/LTE Advanced operating frequencies and future sub-6GHz 5G mobile and wireless communication applications.

As the first 300mm RF SOI foundry solution, 8SW delivers performance, integration and area advantages, with what is claimed to be best-in-class low-noise amplifier (LNA) and switch performance, which collectively improve integration solutions in the front-end module (FEM). The optimized RF FEM platform is tailored to accommodate aggressive LTE and sub-6GHz standards for FEM applications, including 5G Internet of Things (IoT), mobile device and wireless communications.

"At Qorvo, we continuously expand upon our industry-leading RF portfolio to support all pre-5G and 5G architectures, as such we require the best available technologies to enable us to deliver top-notch solutions with the broadest range of connectivity in sub-6GHz and mmWave 5G," states Todd Gillenwater, chief technology officer of Qorvo Inc of Greensboro, NC, USA (which provides core technologies and RF solutions for mobile, infrastructure and defense applications). "GlobalFoundries' 8SW technology delivers a mix of

performance, integration and area advantages in FEM switches and LNAs, giving us a great platform," he comments.

"As new high-speed standards, including 4G LTE and 5G, continue to grow in complexity, innovation in RF front-end radio design must continue to deliver performance commensurate with growing network, data and application demands," says Bami Bastani, senior VP of business units at GlobalFoundries. "GF continuously builds on our extensive RF SOI capabilities that are providing our clients a competitive market advantage with first-time design success, optimal performance, and the shortest time to market," he adds.

According to market research firm Mobile Experts, the mobile RF front-end market will increase at a compound annual growth rate (CAGR) of 8.3% to \$22bn in 2022. With more than 40 billion RF SOI chips shipped through 2018, GF is uniquely positioned to deliver an expanding RF portfolio for a broad range of high-growth applications such as automotive, 5G connectivity and IoT, the firm adds.

"Radio complexity promises to increase for both sub-6GHz and mmWave, driving tight integration of multiple RF functions," says Joe Madden, principal analyst at Mobile Experts. "The market needs RF solutions with high efficiency and linearity performance, but also using scalable processes on large wafers. GlobalFoundries has established an RF SOI process that will enable longer-term market expansion," he comments.

GlobalFoundries presented its 5G-ready RF solutions on 25 February at Mobile World Congress 2019 (MWC19) in Barcelona, Spain (25–28 February).

[www.mwcbarcelona.com](http://www.mwcbarcelona.com)  
[www.globalfoundries.com](http://www.globalfoundries.com)

### IN BRIEF

#### Skyworks and Intel develop 5G solutions

Skyworks Solutions and Intel are creating 5G communications engines for a broad array of end markets. Leveraging Intel's modem expertise and Skyworks' connectivity portfolio, the new platforms will deliver a highly integrated and optimized suite of wireless system solutions for the open market.

Initial modem-to-antenna products will support LTE and 5G architectures for mobile, wearable, automotive, M2M, tablet/PC, smart home and IoT applications, facilitating faster data rates, enhanced power efficiency and unprecedented product footprints. Specifically, designs aim to offer devices that take full advantage of the features and capabilities of Intel's modems, transceivers, power management and envelope tracking chips, while also driving new features to enhance front-end performance.

"Skyworks can fully leverage our front-ends to further enhance modem capability and capitalize on boundless 5G opportunities," says Joel King, senior VP & general manager of Mobile Solutions at Skyworks.

"Our highly synergistic effort with Skyworks to deploy breakthrough system-level, co-optimized solutions is emblematic of Intel's ambitious vision for 5G," says Dr Cormac Conroy, corporate VP & general manager of Intel's Communication and Devices Group.

The co-developed reference design leverages Intel's SMARTi single-chip transceiver and Skyworks' Sky5 suite. With support for 5G, LTE, GPS and Wi-Fi across mobile and IoT markets, the platform will be highly scalable and targeted to all tiers and market verticals.

[www.skyworksin.com/Sky5](http://www.skyworksin.com/Sky5)  
[www.intel.com](http://www.intel.com)

## X-FAB declares full production release of high-voltage galvanic isolation technology

Pure-play analog/mixed-signal and specialty foundry X-FAB Silicon Foundries SE of Tessenlo, Belgium has announced the full volume production release of its new high-temperature galvanic isolation semiconductor process. The proprietary technology is fully automotive qualified, and offers greater reliability levels than options offered by competitors, it is claimed.

Galvanic isolation electrically separates circuits in order to improve noise immunity, remove ground loops, and increase common mode voltage. It can also protect human interfaces from contact with high voltages. An example where this plays an important role is the control of insulated-gate bipolar transistor (IGBT) or silicon carbide (SiC) power modules in industrial and automotive environments. Further

applications include data communication in field bus systems, battery management systems or medical equipment.

Advantages of the new galvanic isolation process include:

- operational temperatures of up to 175°C;
- successfully tested up to 6000V<sub>rms</sub> @ 50Hz and 10,000V<sub>DC</sub>;
- uninterrupted barrier layer with 0ppm residual contamination;
- demonstrated conformance with the latest IEC 60747-17 semiconductor coupler draft standard; and
- support for working voltages up to 1.7kV.

X-FAB offers two types of packaged galvanic isolation devices for customer evaluation. The capacitive coupler test chip (G3-C1) has an isolation layer thickness of

11µm and was tested to withstand up to 6000V<sub>rms</sub> (the maximum limit of the test setup). An inductive coupler test chip (G3-T06) is also available for customer evaluation and has an isolation layer thickness of 14µm.

The new galvanic isolation technology is manufactured at X-FAB's Dresden facility, which is certified for automotive manufacturing in accordance with the IATF-16949: 2016 International Automotive Quality Management System (QMS) standard.

Design kits for all major electronic design automation (EDA) platforms can be downloaded from X-FAB's customer web portal.

Samples can be supplied on request. Full process qualification reports are also available.

[www.xfab.com](http://www.xfab.com)

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# Pivotal selects MACOM as RF component supplier for Echo 5G in-building penetration device

MACOM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) says that its mmWave products — manufactured with its gallium arsenide (GaAs) and aluminium gallium arsenide

(AlGaAs) process technology — have been integration into the Echo 5G product line of Pivotal Commware Inc of Kirkland, WA, USA (which develops communications platforms, systems and applications based on its Holographic Beam Forming technology).

The window-mounted, self-installable Echo 5G Subscriber product, for example, can overcome the biggest obstacle to fixed 5G wireless access at millimeter waves — in-building penetration of Gigabit speed broadband to homes and businesses. Holographic Beam Forming allows Echo 5G to penetrate Low-E glass coatings and multiple panes of glass using very little power, which drives its low weight and size profile on the window. MACOM's mmWave technology leverages and extends these capabilities.

MACOM says that 5G at mmWave frequencies has catalyzed an explosion in demand for coverage and throughput of broadband wireless access with speeds in excess of 1Gb/s. To meet demand for time to market, cost and performance, RF device providers need to work intimately with system architects to achieve the optimum solution for the end applications, the firm adds.

"Power handling, efficiency, insertion loss and channel isolation are major challenges for RF components at mmWave frequencies,"



says Pivotal's CEO Brian Deutsch. "MACOM's products and technology overcomes these challenges and will ensure that the Echo 5G product line facilitates not only 5G fixed wireless in-building penetration and subscriber self-installation but also the cost-effective extension, redirection and shaping of 5G network coverage on demand and with low latency. Carriers will see huge savings on base-station deployment CapEx and on the OpEx that goes with them," he adds. "With the Echo 5G product line, wireless carriers achieve the cost economics allowing them to effectively compete against wired broadband service incumbents," Deutsch claims.

"Pivotal's Echo 5G Subscriber and Network products will be game-changers for the wireless carriers who deploy them," believes MACOM's president & CEO John Croteau. "MACOM's broad portfolio of amplification, signal generation and control components across the microwave and mmWave spectrum — coupled with our unmatched heterolithic integration capabilities — offer the industry's lowest insertion loss and best noise figure, providing superior reception for macrocell base stations and fixed wireless access points," he claims.

[www.pivotalcommware.com/markets/4g-and-5g](http://www.pivotalcommware.com/markets/4g-and-5g)  
[www.macom.com](http://www.macom.com)

## IN BRIEF

### ROHM Semi appoints product marketing manager for power management ICs

Japan's ROHM Semiconductor has appointed Michael Maurer as product marketing manager for power management ICs, advancing the firm's further expansion of business relations in Europe.

As well as having a Master's degree in telecommunications from the University of Applied Sciences Esslingen, Germany, Maurer has more than 30 years of experience in high-tech companies. He began his career in 1988 as a hardware/software developer at Alcatel, where he also worked as a project manager, product and technical marketing manager. This was followed by positions as product, technical and strategic marketing manager at Dialog Semiconductor. Most recently he was director Engineering Services at mm-lab GmbH.



"Maurer not only brings a great deal of know-how for the technology and the industry itself, but also an extensive network," comments Günter Richard, director marketing at ROHM Semiconductor Europe of Willich-Münchheide, near Düsseldorf, Germany, which serves the EMEA (Europe, Middle East and Africa) region. "With his support, we will continue to successfully expand in the automotive and power management sectors," he adds.

[www.rohm.com/eu](http://www.rohm.com/eu)

## ST acquiring majority stake in SiC wafer maker Norstel

### Control of supply chain to strengthen flexibility to serve automotive and industrial applications

STMicroelectronics of Geneva, Switzerland has signed an agreement to acquire a majority stake in Norstel AB of Norrköping, Sweden, which was spun off from Linköping University in 2005 and develops and manufactures 150mm silicon carbide (SiC) bare and epitaxial wafers. ST says that, after closing, it will control the entire supply chain for a portion of its SiC devices at a time of constrained global capacity and position itself for a significant growth opportunity.

ST will acquire 55% of Norstel's share capital, with an option to acquire the remaining 45% subject

to certain conditions, which, if exercised, will result in total consideration of \$137.5m, funded with available cash.

"ST is the only semiconductor company with automotive-grade silicon carbide in mass production today," claims

**Acquisition of a majority stake in Norstel will boost our flexibility, improve yield and quality, and support our long-term silicon carbide roadmap and business**

president & CEO Jean-Marc Chery. "We want to build on our strong momentum in SiC, both in volume and breadth of applications for industrial and automotive, targeting continued leadership in a market estimated at more than \$3bn in 2025," he adds. "The acquisition of a majority stake in Norstel is another step forward strengthening our silicon carbide ecosystem: it will boost our flexibility, improve yield and quality, and support our long-term silicon carbide roadmap and business."

[www.norstel.com](http://www.norstel.com)  
[www.st.com](http://www.st.com)

## Littelfuse launches its first 650V SiC Schottky diodes

Littelfuse Inc of Chicago, IL, USA, which provides circuit protection technologies (including fuses, semiconductors, polymers, ceramics, relays and sensors), has launched the LSIC2SD065CxxA and LSIC2SD065AxxA Series second-generation series of 650V, AEC-Q101-qualified silicon carbide (SiC) Schottky diodes.

Available with a choice of current ratings (6A, 8A, 10A, 16A or 20A), they offer power electronics system designers a variety of performance advantages, including negligible reverse recovery current, high surge capability and a maximum operating junction temperature of 175°C, so they are suitable for applications that require enhanced efficiency, reliability and thermal management.

Compared with standard silicon PN-junction diodes, the 650V Series SiC Schottky diodes support dramatic reductions in switching losses and substantial increases in the efficiency and robustness of a power electronics system. Because they dissipate less energy and can operate at higher junction temperatures than Si-based solutions, they

allow for smaller heat sinks and a smaller system footprint, providing end-users with the advantages of more compact, energy-efficient systems and the potential for a lower total cost of ownership.

Typical applications for 650V Series SiC Schottky diodes include: power factor correction (PFC), buck/boost stages in DC-DC converters, free-wheeling diodes in inverter stages, high-frequency output rectification, and electric vehicle (EV) applications.

"These new series are our first 650V SiC Schottky diode offerings; all our previous releases were 1200V-rated devices, so we can now address a wider range of applications and further complement the Littelfuse SiC MOSFET portfolio," says Christophe Warin, Silicon Carbide product marketing manager in Littelfuse's Semiconductor business unit. "Their AEC-Q101 qualification puts these diodes in a higher class than similar devices in terms of quality and reliability," he adds.

The 650V Series SiC Schottky diodes are said to offer the following benefits:

- AEC-Q101-qualified diodes exhibit exceptional performance in demanding applications.
- Far lower switching losses than silicon bipolar diodes and fast, temperature-independent switching behavior make the devices suitable for high-frequency power switching.
- The positive temperature coefficient enables safe operation and ease of paralleling.
- The 175°C maximum operating junction temperature provides a larger design margin and relaxed thermal management requirements.

LSIC2SD065CxxA Series SiC Schottky diodes are available in TO-252-2L (DPAK) packages, in tape & reel format, with a minimum order quantity of 2500 devices.

LSIC2SD065AxxA Series SiC Schottky diodes are available in TO-220-2L packages, with 50 devices packed in a tube, with a minimum order quantity of 1000 units.

Sample requests may be placed through authorized Littelfuse distributors worldwide.

[www.littelfuse.com](http://www.littelfuse.com)

# II-VI to supply 200mm SiC substrates for REACTION

## European Commission's Horizon 2020 program

### Program to establish first 200mm pilot production facility for SiC-based power electronics

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA, which provides silicon carbide (SiC) substrates for power electronics, is to supply 200mm silicon carbide substrates under REACTION, a Horizon 2020 four-year program funded by the European Commission.

The Horizon 2020 program's goal is to establish in Europe the world's first 200mm pilot production facility for power electronics based on SiC, an advance on the existing standard of 150mm. Through this program, the European Commission is investing in the capabilities required to scale up production of SiC-based power electronics. SiC

achieves superior efficiency, higher energy density and lower system-level cost per watt. Power electronics based on SiC have demonstrated their potential to have a highly beneficial impact on the environment via significant reductions in carbon-dioxide emissions.

"II-VI introduced the world's first 200mm SiC substrates in 2015," says Martin Benzing, managing director, II-VI GmbH. "The strength of II-VI's technology platform is based on a strong portfolio of 30 active patents and on highly differentiated and proprietary manufacturing platforms and technologies," he adds.

Participants in the REACTION Horizon 2020 program represent the entire value chain for power electronics. The mission is to demonstrate the possibility of scaling the mass production of 200mm substrates for SiC devices in power applications ranging from 600V to 3.3kV. The ultimate goal is to achieve the cost, performance and size requirements that will enable their broad adoption in emerging clean technology applications, including in electric cars, renewable energy systems and smart power grids.

[www.iivadvmat.com](http://www.iivadvmat.com)

[www.ii-vi.com/sic-substrates-2/?SingleProduct=673](http://www.ii-vi.com/sic-substrates-2/?SingleProduct=673)

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# US DOE's ARPA-E awards \$35m to 12 new projects to support medium-voltage devices

## Focus on SiC and GaN devices for kilovolt DC power management

The US Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) has awarded \$35m in funding for 12 projects seeking new ways to harness medium-voltage electricity for applications in industry, transportation, on the grid and beyond. The selected projects are part of ARPA-E's program 'Building Reliable Electronics to Achieve Kilovolt Effective Ratings Safely' (BREAKERS), as well as the latest OPEN+ cohort 'Kilovolt Devices'.

"America's energy landscape is constantly evolving, and as new ways to generate and distribute power gain popularity, it's critical we develop the tools to maximize their utility," comments US Secretary of Energy Rick Perry. "These ARPA-E projects serve first and foremost to modernize how we move power around safely, reliably and efficiently, creating a new set of capabilities for tomorrow's utilities and industry."

The eight BREAKERS projects will work to develop new direct current (DC) devices to better manage power by eliminating electrical faults, improving efficiency and reaction times, and potentially enabling greater proliferation of energy storage and renewable resources.

The four Kilovolt Devices OPEN+ projects will focus on challenges facing power electronics in the medium-voltage space, with a particular eye toward grid security and reliability.

Existing power distribution networks are primarily powered by alternating current (AC) electricity, but DC can provide lower distribution losses and higher power-carrying capacity. BREAKERS projects will develop DC devices that prevent electric arcing, a safety hazard, while handling large amounts of power and voltage.

It is reckoned that medium-voltage DC circuit breakers could enable significant improvements in the USA's

electrical system, transforming how electricity is delivered and managed across the entire power grid, as well as critical applications in industry, transportation and resource production.

### **BREAKERS projects include:**

- **Ultra-Efficient Intelligent MVDC Hybrid Circuit Breaker (\$4,413,913).** Drexel University aims to design a significantly more efficient, fast, low-cost, compact, and reliable circuit breaker for medium-voltage direct-current (MVDC) power system. The breaker is designed to protect MVDC systems from electrical faults and expected to respond in 500\_μs. Drexel hence proposes a solid-state circuit breaker based on silicon carbide (SiC) devices that aims to significantly improve breaker performance for the MVDC ecosystem.

- **DC Wide Bandgap Static Circuit Breaker (\$3,760,000).** Eaton Corp will develop a SiC-based direct-current circuit breaker design that boosts efficiency and can scale up or down medium-voltage application requirements. The comprehensive approach includes a robust design that effectively dissipates excess energy and autonomously coordinates fault protection across multiple devices. Results will extend to future ultra-wide-bandgap power semiconductor devices and other advances affecting future generations of devices and power electronics.

- **Ultra-Fast Resonant DC Breaker (\$500,000).** Marquette University will develop a DC breaker combining the advantages of a vacuum interrupter with a wide-bandgap-based resonant current source and novel actuator topology. The proposed solution represents a transformational DC breaker scalable across voltage and current in medium-voltage DC applications, such as power distribution, solar, wind, and electric vehicles.

- **T-Type Modular DC Circuit Breaker (T-Breaker) for Future DC Networks (\$2,309,950).** Ohio State University will develop a MVDC circuit breaker prototype based on a modular design using SiC modules to reduce cost and weight while enabling simpler manufacturing, increased reliability, functionality, efficiency and power density. The modular structure will be self-sustaining and allow for inherent scalability while providing possibilities for multiple ancillary functions.

- **ARC-SAFE: Accelerated Response semiconducting Contactors and Surge Attenuation for DC Electrical systems (\$2,250,000).** Sandia National Laboratories will develop a solid-state circuit breaker for medium-to-high-voltage applications using switches based on the wide-bandgap semiconductors silicon carbide (SiC) and gallium nitride (GaN). The concept builds on Sandia's knowledge of optically triggered GaN devices, as well as the team's experience in circuit design for medium-voltage (MV) applications. Sandia will build a prototype breaker to demonstrate a fast response time using a photoconductive switch that is potentially scalable from 1kV to 100kV for DC systems. This technology could contribute to more widespread adoption of MVDC power distribution across the grid.

### **OPEN+ Kilovolt Devices projects include:**

- **Advanced Medium Voltage SiC-SJ FETs with Ultra-Low On-Resistance (\$3,090,746).** GE Global Research will develop a device architecture for the first high-voltage SiC superjunction (SJ) field-effect transistors, which will provide highly efficient power conversion (such as from direct to alternating current) in medium-voltage applications, including renewables like solar and wind power, as well as transportation. The transistors will scale to high voltage while offering up to 10 times

lower losses compared with commercial silicon-based transistors available today.

● **GaN MOCVD Growth on Native Substrates for High Voltage (15–20kV) Vertical Power Devices (\$2,211,712).** Ohio State University will develop GaN materials suitable for high-voltage (15–20 kV) power control and conversion. The team will develop a unique method to grow thick GaN films with low background impurity contamination, necessary to allow high-voltage operation with high efficiency. The thick GaN layers will be deposited on high-quality bulk GaN base materials with reduced defects, critical to depositing high-quality GaN films on top, and perform high-voltage device design, fabrication and testing to provide feedback for further GaN material growth and optimization.

● **20kV Gallium Nitride pn Diode Electro-Magnetic Pulse Arrestor for Grid Reliability (\$5,415,000).** Sandia National Laboratories will develop a new device to prevent damage to the power grid caused by electromagnetic pulse (EMP). The EMP arrestor will comprise diodes fabricated from GaN, capable of responding on the nanosecond timescale required to protect the grid against EMP threats. It will be capable of blocking 20kV, enabling a single device to protect distribution-level equipment on the grid. The team will focus on GaN crystal growth and device design to achieve the 20kV performance target. It will also create a pilot production line to serve as a model for eventual commercial production.

● **20kV GaN Switch Technology Demonstrated in High-Efficiency**

Medium-Voltage Building Block (\$3,000,000). Virginia Tech will accelerate deployment of power electronics into grid-scale energy applications by developing 20kV GaN devices integrated into a medium-voltage power module. High-quality substrates and innovative growth techniques will be used to reduce the background impurity contamination in the thick layers needed to block 20kV. The power module will be fabricated using 3D packaging for improved thermal management and high power density at 20kV. The module will enable the full potential of high-voltage, high-temperature and fast-switching GaN devices in medium-voltage power converters for use in renewable energy grid-level applications and transportation.

<https://arpa-e.energy.gov>

## JEDEC wide-bandgap power semiconductor committee publishes first document

The JEDEC Solid State Technology Association (which develops standards for the microelectronics industry) says that its newest main committee, JC-70 (Wide Bandgap Power Electronic Conversion Semiconductors'), has issued its first publication — JEP173: Dynamic On-Resistance Test Method Guidelines for GaN HEMT Based Power Conversion Devices — available for free download from its website.

JEP173 addresses a key need of the user community of gallium nitride (GaN) power field-effect transistors (FETs), namely a method for the consistent measurement of drain-to-source resistance in the ON-state (RDS(ON)) encompassing dynamic effects. These dynamic effects are characteristic of GaN power FETs, and the value of the resulting measured RDS(ON) is method dependent.

"JEP173 demonstrates how quickly the GaN industry came together to address this important topic and begin to establish standards across suppliers for

datasheet, qualification and test methods," says JC-70's chair Stephanie Watts Butler, technology innovation architect at Texas Instruments. "The release of JEP173 will help accelerate industry-wide adoption of GaN by ensuring consistency across the supplier base."

Formed in October 2017 with 23 member companies, JC-70 now has over 50 member companies, underscoring industry interest in the development of universal standards to help advance the adoption of wide-bandgap (WBG) power technologies. Global multi-national corporations and technology startups from the USA, Europe, Middle East and Asia are working together to bring to the industry a set of standards for reliability, testing and parametrics of WBG power semiconductors. Committee members include industry leaders in power GaN and SiC semiconductors, as well as prospective users of wide-bandgap power devices, and test & measurement equipment suppliers.

Technical experts from universities and national labs also provided inputs into the new JEP173 guideline.

"Strong commitment from the committee members was required to complete this work to set up universal standards to help advance the adoption of wide-bandgap power technologies," comments Tim McDonald, senior advisor to Infineon's CoolGaN program and the chair of the JC-70.1 subcommittee. "Our Task Groups are diligently making progress on other key GaN and SiC guidelines in the areas of test, reliability and datasheets."

Interested companies worldwide are welcome to join JEDEC to participate in the standardization effort. JC-70 plans to hold four committee meetings in 2019, including a meeting co-located with the IEEE Applied Power Electronics Conference and Exposition (APEC 2019) in Anaheim, CA, USA on 18 March.

[www.jedec.org](http://www.jedec.org)

## PSMA-sponsored Industry Sessions at APEC address 'Coming of Age' of wide-bandgap power semiconductors

The Power Sources Manufacturers Association (PSMA) Semiconductor Committee is sponsoring a series of three Industry Sessions on 19–21 March at the IEEE Applied Power Electronics Conference and Exposition (APEC 2019) in the Anaheim Convention Center in California that address the rapid emergence of wide-bandgap semiconductors as a significant power conversion technology.

Taken as a whole, the series of Industry Sessions will address the 'Coming of Age' of gallium nitride (GaN) and silicon carbide (SiC) power semiconductors, with each session focusing on one aspect of the topic:

- IS4: 19 March (8:30–11:55am) 'Getting up to speed on switching: wide bandgap and other high-performance components';
  - IS11: 20 March (2–5:25pm) 'Current reliability and product qualification topics for SiC and GaN wide bandgap devices';
  - IS16: 21 March (8:30–11:30am) 'Production use cases of wide bandgap semiconductors: systems in production today, drivers and controllers for tomorrow'.
- "SiC and GaN have been the most popular topics at APEC over the past several years. It is clear that the promise that these devices have offered in size and efficiency gains are being realized," comments

PSMA Semiconductor Committee chairman Tim McDonald. "This 'Coming of Age' series of Industry Sessions will serve to inform attendees on this vital technology area," he adds. In addition to presentations, the Industry Sessions will enable attendees to interact and network with industry colleagues engaged in power conversion system design.

All APEC attendees are invited to attend the PSMA Semiconductor Committee meeting on Wednesday 20 March (8–10am) in the Marriott Hotel (Meeting Room Platinum 10).

[www.pdma.com](http://www.pdma.com)

[www.apec-conf.org/industrysessions](http://www.apec-conf.org/industrysessions)

## MACOM and ST expanding 150mm GaN-on-Si production capacity, and 200mm as demand requires

### Wafer supply expansion to enable cost, scale and industrialization of GaN-on-Si for global 5G network buildout

MACOM Technology Solutions Inc of Lowell, MA, USA (which makes semiconductors, components and subassemblies for RF, microwave, millimeter-wave and lightwave applications) and STMicroelectronics of Geneva, Switzerland have announced the 2019 expansion of 150mm GaN-on-silicon production capacity in ST's fabs (and 200mm as demand requires) to service the worldwide 5G telecom buildout. This builds on the broad GaN-on-Si agreement between MACOM and ST announced in February 2018.

The global rollout of 5G networks and move to massive multiple-input, multiple-output (M-MIMO) antenna configurations is expected to create a substantial increase in the demand for RF power products. Specifically, MACOM estimates there will be a 32-64x increase in the number of power amplifiers required, more than tripling the dollar content over a five-year cycle



station OEMs understand they need wide-bandgap GaN performance with transformational cost structures and manufacturing capacity to meet 5G antenna cost, range and energy efficiency targets in the field," says MACOM's president & CEO John Croteau. "By teaming with ST, we believe MACOM is uniquely poised to provide it all — performance, cost and high-volume

of 5G infrastructure investment and driving an estimated 10-20x decrease in the cost per amplifier. "Major base-

supply chain... Our joint investment at this early stage in bringing on more capacity positions us to service up to 85% of the global 5G network buildout," he believes.

"ST has built a strong foundation as a global leader in silicon carbide and we are now moving forward with RF GaN-on-silicon, which will enable OEMs to build a new generation of high-performance 5G networks," says Marco Monti, president of STMicroelectronics' Automotive and Discrete Product Group. "While silicon carbide is ideal for certain power applications such as automotive power conversion, GaN-on-Si provides the necessary RF performance, scale and commercial cost structures to make 5G a reality," he adds. "With this move ST and MACOM aim to unlock the industry bottleneck and fulfill the demand for 5G buildouts."

[www.st.com](http://www.st.com)

[www.macom.com/gan](http://www.macom.com/gan)

# Fuji Electric Lambda Series Safety, Compact, Powerful



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## Digi-Key to provide global online distribution of Navitas' GaNFast power ICs

Navitas Semiconductor Inc of El Segundo, CA, USA and global, full-service component distributor Digi-Key Electronics of Thief River Falls, MN, USA have announced a distribution agreement to provide worldwide, 24-hour availability and accelerate market penetration and revenue ramp of GaNFast power ICs.

Founded in 2014, Navitas introduced what it claimed to be the first commercial GaN power ICs. The firm says that its proprietary 'AllGaN' process design kit (PDK) monolithically integrates GaN power field-effect transistors (FETs) with GaN logic and analog circuits, enabling smaller, higher-energy-efficiency and lower-cost power for mobile, consumer, enterprise and new energy markets.

The GaNFast power ICs enable power systems to simultaneously achieve MHz-frequency and high-efficiency operation. This translates to smaller, faster, lighter and lower-cost power conversion in mobile fast chargers and adapters, the Internet of Things (IoT), TVs, electric/hybrid electric vehicles (EV/HEV), LED lighting and new energy solutions.

"GaNFast ICs are the ideal, easy-to-use, robust, 'digital-in, power-out' solution and now, with Digi-Key's best-in-class service, this technology is readily available to every power electronics designer around the world," says Stephen Oliver, VP of sales & marketing.

The NV6113, NV6115 and NV6117 single GaNFast power ICs are 650V-

rated and available in 5mm x 6mm QFN packages. A series of videos and technical papers introduces GaNFast technology, applications and end-customer examples. Product datasheets and application-specific design kits enable fast implementation for new and upgraded designs.

"Integrating the GaN gate driver, GaN FET and GaN logic into a single package simplifies the circuit design," says David Stein, VP of global supplier management at Digi-Key. "Our 24/7 global support network with the integration of GaNFast power ICs will be a powerful combination to accelerate the development of a new class of power systems."

[www.digikey.com/en/supplier-centers/n/navitas-semiconductor](http://www.digikey.com/en/supplier-centers/n/navitas-semiconductor)

## EPC issues tenth reliability report, highlighting GaN device testing beyond automotive AECQ101 qualification

Efficient Power Conversion Corp (EPC) of El Segundo, CA, USA – which makes enhancement-mode gallium nitride on silicon (eGaN) power field-effect transistors (FETs) for power management applications – has announced its Phase Ten Reliability Report, documenting the test results leading to the completion of automotive AEC-Q101 qualification.

AEC-Q101 demands the highest level of reliability standards for power FETs, requiring not only zero datasheet failures but also low parametric drift during stress testing. EPC's wafer-level chip-scale packaging (WLCS) passed all the same testing standards created for conventionally packaged parts, demonstrating that the superior performance of chip-scale packaging does not compromise ruggedness or reliability.

The report also explores reliability testing that goes beyond the AEC-Q101 requirement to develop a

deeper understanding of unique mechanisms that could lead to device failure. A section is devoted to examining the extremes of dynamic RDS(on) testing during hard-switching conditions. This testing demonstrates that eGaN devices are stable over long-term continuous switching operation, says EPC.

A third section expands on the accelerated stress testing previously explored in the EPC Phase 6 report. Beyond gate leakage being monitored continuously, other device parameters (VTH and IDSS) are logged on regular intervals. This kind of data gives a more complete picture of device degradation under high-gate-stress conditions and provides visibility to multiple independent physical failure mechanisms. Testing demonstrates that eGaN FET gates are very rugged and reliable. "eGaN devices have been in volume production for over nine years and have demonstrated

very high reliability in both laboratory testing and customer applications such as LiDAR [light detection & ranging] for autonomous cars, 4G base stations and satellites to name just a few," says CEO & co-founder Dr Alex Lidow. "In fact, there have been no field failures in over two years despite shipping millions of parts."

"With the release of this reliability report, we continue our commitment to subject GaN devices to rigid industry standards and share the results with the power conversion industry – as confirmed with over 30,000 EPC parts stress-tested for more than 18 million hours without failure," Lidow continues. "The Phase Ten Reliability Report adds to the growing knowledge base published in EPC's first nine reports and represents an ongoing commitment to study, learn and share information on the reliability of GaN technology."

[www.epc-co.com](http://www.epc-co.com)



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# Transphorm releases quality and reliability data behind device shipment numbers

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — has announced the first complete validation data set for GaN power FETs in the range 600V and higher. This information expands on Transphorm's announcement in December indicating that it has shipped over 250,000 GaN FETs to date.

"In the power conversion market, quality, reliability and performance are the three main factors used when vetting transistors," says Philip Zuk, VP of technical marketing worldwide. "We've always operated with the mindset that prioritizing quality and reliability will result in high-voltage GaN's success," he adds. "We're proud to see that strategy deliver positive results and felt it important to release the validation data so that potential and existing customers can understand GaN's true capabilities."

Availability of the two new data types, Early Life Failure (ELF) and Field Failure, that round out the validation data set marks another milestone for high-voltage GaN technology, says the firm, further positioning its GaN reliability as competitive to and poised to likely surpass that of alternative solutions — silicon and silicon carbide (SiC) — given that Transphorm's power conversion technology is in its first maturation stage whereas silicon transistors have long-since matured and SiC is a decade into its development.

## High-voltage GaN reliability: a complete view

Transphorm's complete data set includes five components of product reliability:

- Product Qualification: defined by JEDEC and AEC-Q101 standards.

- Testing beyond standard requirements: includes high-voltage switching, single-event burnout (SEB), high-temperature operation lifetime (HTOL) and high-temperature gate bias (HTGB) testing at elevated temperatures and voltages.

- Intrinsic Lifetime: measures device's 'wear-out' lifetime; also defines failure modes and acceleration factors.

- Extrinsic Lifetime or ELF: forecasts field failure rates in failure in time (FIT) or parts per million (ppm) per year rates; used for warranty calculations.

- Field Failure: measures a device's actual field performance in customer applications.

"Intrinsic data alone is not enough," states Ron Barr, VP of quality and reliability. "Intrinsic testing gives us the acceleration factors that we use in conjunction with Early Life Failure testing to determine the product's infant mortality rate. This makes it easy for customers to accurately vet GaN devices. Pairing intrinsic data with extrinsic data and Field Failure rates provides a complete baseline for how GaN FETs will perform."

**Intrinsic testing gives us the acceleration factors that we use in conjunction with Early Life Failure testing to determine the product's infant mortality rate. This makes it easy for customers to accurately vet GaN devices. Pairing intrinsic data with extrinsic data and Field Failure rates provides a complete baseline for how GaN FETs will perform**

## Extrinsic Early Lifetime Failure

Intrinsic failure rates give unrealistically optimistic views of product reliability, says Transphorm. ELF (Infant Mortality) provides the most realistic view via FIT and ppm rates. Early Lifetime Failure assesses potential defects in materials, design and process control that may cause parts to fail. Notably, ELF causes most customer warranty claims and typically occurs sooner and at higher rates than wear-out failures. Given this, customers use ELF data to determine warranty risks and costs. Transphorm's ELF is: 0.45 FIT; 4ppm.

## Field Failure

Field Failure measures the number of devices that fail in customer systems in production in relation to the total number of parts sold. Transphorm has shipped over 250,000 FETs and accumulated over 1.3 billion field hours of operation, resulting in the following Field Failure rates: 3.1 FIT; 27.4 ppm (conservative estimate)

Transphorm says that its Field Failures align with that of SiC, which is reported to be less than 5 FIT. Further, the firm's ppm rate continues to decrease over time regardless of application, suggesting that reliability is better than currently reported.

Intrinsic Lifetime is essentially a device's theoretical lifetime, assuming that material wear-out is the only contributor to the part's longevity. The data is created using the 'Physics of Failure' methodology, which involves measuring time to failure when stressing parts with voltage and temperature, and building related models used to predict ultimate lifetime.

## Transphorm's Intrinsic GaN wear-out:

- mean time before failure [MTBF] = 1e11 hours [11m+ years];
- lifetime [100ppm] = 100m hours [11,415 years].

[www.transphormusa.com/en/](http://www.transphormusa.com/en/)

## Transphorm GaN FET used in TDK-Lambda's latest-generation AC-DC power supply module

Transphorm Inc of Goleta, near Santa Barbara, CA, USA — which designs and manufactures JEDEC- and AEC-Q101-qualified high-voltage (HV) gallium nitride (GaN) field-effect transistors (FETs) for high-voltage (HV) power conversion applications — says that TDK-Lambda Corp (a group company of TDK Corp that makes power supplies for industrial equipment) has released its first GaN-based AC-DC power supply.

The full-function 504W-rated PFH500F-28 is TDK-Lambda's latest-generation AC-DC baseplate-cooled power supply module. Further, it is the latest Transphorm customer product to demonstrate the HV GaN advantages, increasing power efficiency by 5% in a 28% smaller package over the previous PFE500F series.

The PFH500F-28 is a low-profile power module with 28V of output power designed for various harsh-environment applications, commercial off-the-shelf (COTS) power supplies, custom fanless power supplies, traffic signaling, and more. TDK-Lambda's redesigned standard power module uses a bridgeless totem-pole power factor correction (PFC) topology to optimize Transphorm's TPH3206LDG FET in the popular 8x8 PQFN package.



**TDK-Lambda's PFH500F-28 AC-DC power supply module uses Transphorm's GaN modules for a 30% power density increase.**

The development project was led by the TDK-Lambda Americas Dallas, TX team and leveraged Transphorm's application support team throughout various phases of the three-year initiative.

"Our engineers diligently review new technologies that will benefit our end customers to ensure any new product we release is reliable and a notable advancement over prior models," says TDK-Lambda's VP of engineering Jin He. "Our decision to work with Transphorm on our first GaN AC-DC product was based largely on the power semiconductors' proven quality and reliability as well as the team's reputation for successful collabor-

ation," he adds. "Our experience was such that we've released the PFH500F-28 with our three-year warranty and are in discussions with Transphorm regarding future projects."

Transphorm says that its GaN to date has enabled customers to produce computing power supplies, servo motors and telecom power supplies that show advantages in power density, size and system cost. TDK-Lambda's power module joins them, as the PFH500F-28 delivers the

following advantages compared with its silicon-based predecessor:

- power efficiency up to 92% (5% more than the PFE500F);
- power density of 100W/cubic inch (30% up on the PFE500F);
- PMBus monitoring and programming (read/write);
- size reduction of 28% (from 122mm x 70mm x 12.7mm to 101.6mm x 61mm x 13.5mm);
- reduced size of external capacitive components; and
- thermal impact: a 38% reduction in waste heat (requiring less heatsink/cooling than the PFE500F).

[www.transphormusa.com/design-resources](http://www.transphormusa.com/design-resources)

## RFHIC signs \$54m multi-quarter deal to buy GaN-on-SiC HEMT transistors from Wolfspeed

RFHIC Corp of Anyang, South Korea (which designs and makes active RF & microwave high-power components and hybrid modules for telecoms, defense industries, consumer goods and customized solutions) has signed a multi-quarter agreement worth a minimum of \$54m to purchase gallium nitride on silicon carbide (GaN-on-SiC) high-electron-mobility transistors

(HEMTs) from Cree company Wolfspeed of Durham, NC, USA.

RFHIC says that the agreement solidifies the collaboration between the two firms to expand its growing share of the RF market, including upcoming 5G applications. RFHIC has commercialized GaN-based RF power transistors and power amplifiers for 4G LTE networks and expects to continue this role in the

5G market.

"This agreement with Wolfspeed will help us meet our customers' ever-increasing demand for higher capacity and performance of our RF solutions, and long-term visibility," believes RFHIC's chief technology officer & chairman Samuel Cho.

[www.rfhic.com](http://www.rfhic.com)  
[www.wolfspeed.com/RF](http://www.wolfspeed.com/RF)

# Diamond D-Day workshop gives progress update on GaN-on-diamond microwave technology

On 29 January in the one-day workshop 'Diamond D-Day' organized by the Centre for Device Thermography and Reliability (CDTR, part of the University of Bristol's School of Physics), scientists from around the world heard progress on gallium nitride (GaN)-on-diamond microwave technology.

It is reckoned that this next-generation technology will underpin future high-power radio frequency and microwave communications, space and defence systems, paving the way towards 5G and 6G mobile phone networks and much more comprehensive radar systems.

Bristol is working with a consortium of four other UK universities (Cardiff, Glasgow, Cambridge and Birmingham) as well as industry partners in the five-year (2017–2021) program GaN-DaME (Integrated GaN-Diamond Microwave Electronics: From Materials, Transistors to MMICs), which received a £4.3m grant from the UK Engineering and Physical Sciences Research Council (EPSRC) at the beginning of 2017.

Plenary speakers at the workshop included the USA's Akash Systems Inc, the Universities of Bristol and Cardiff, the European Space Agency USA in The Netherlands/UK, Germany's Fraunhofer Institute, Qorvo Inc and Raytheon in the USA, RHFIC Corp of SouthKorea/USA and Austria's RHP-Technology GmbH.

"120 participants, with more than 50% from outside the UK as far

away as the US, China, Japan and Australia, learned about the latest developments in this exciting new device technology for future 5G and security applications," said Bristol's professor Martin Kuball, the academic lead for the project.

GaN-DaME's vision is to develop transformative GaN-on-diamond high-electron-mobility transistors (HEMTs) and monolithic microwave integrated circuits (MMICs) as the technology step beyond existing microwave devices (such as GaN-on-SiC), revolutionizing the thermal management that presently limits GaN electronics.

Energy flows in these can be as high as the heat flux on the surface of the sun, and diamond — due to its ultra-high thermal conductivity — is the only material that can handle them. These devices can allow the implementation of future communications networks and radar systems with capabilities beyond what is presently possible, it is expected.

"To enable our vision to become reality, we develop new diamond growth approaches that maximize diamond thermal conductivity close to the active GaN device area," says Kuball. "In present GaN-on-diamond devices, a thin amorphous dielectric layer is required on the GaN surface to enable seeding and successful deposition of diamond onto the GaN. Unfortunately, most of the thermal barrier in these devices then exists at this GaN-dielectric-

diamond interface, which has much poorer thermal conductivity than desired," he adds. "Any reduction in this thermal resistance would be of huge benefit. This we achieved by using new crystalline seeding layers for the diamond. Novel diamond growth is combined with innovative micro-fluidics using phase-change materials, a dramatically more powerful approach than conventional micro-fluidics, to further aid heat extraction."

"The outcome are devices with a spectacular >5x increase in RF power compared to the current state-of-the-art GaN-on-silicon carbide HEMTs, presently commercially available," Kuball continues.

"Alternatively, and equally valuably, a dramatic 'step-change' shrinkage in MMIC or power amplifier (PA) size is possible, delivering an increase in efficiency through the removal of combining networks as well as a reduction in power amplifier cost," he adds.

"This represents a disruptive change in capability that will allow the realisation of new system architectures — for example, for radio-frequency seekers and medical applications, and enable the bandwidths needed to deliver 5G and beyond. Reduced requirements for cooling/increased reliability will result in major cost savings at the system level," Kuball concludes.

[www.bristol.ac.uk/physics/research/cdtr/epsrc-programme-grant-gan-dame](http://www.bristol.ac.uk/physics/research/cdtr/epsrc-programme-grant-gan-dame)

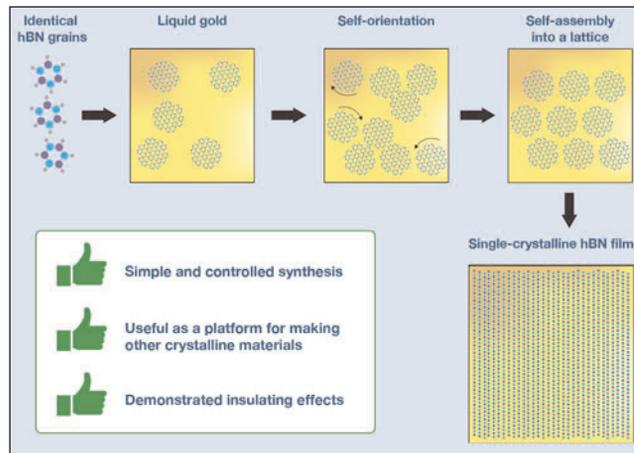
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# Synthesizing single-crystalline hexagonal boron nitride film that uniformly self-assembles

## Films could be used as substrate for single-crystal growth of other diatomic two-dimensional materials

Researchers at South Korea's Dongguk University (led by professor Ki Kang Kim) in collaboration with other institutes — the Korea Institute of Science and Technology (KIST) and Sungkyunkwan University — have developed a method for synthesizing hexagonal boron nitride (hBN) films with a nearly perfect single-crystalline structure (Joo Song Lee et al, 'Wafer-scale single-crystal hexagonal boron nitride film via self-collimated grain formation', *Science* vol362, issue 6416, p817–821). This structure consistently self-assembles on top of liquid gold and can then be used as a platform for synthesizing other crystalline thin-film materials such as graphene.

Synthesizing perfect crystalline structures is very challenging, with most methods yielding crystals with defects or with multiple different basic units (polycrystals). Hexagonal boron nitride (also called white graphite) can be synthesized in the shape of crystalline films with the width of a single atom. These have an insulating effect that has found uses in various types of research. However, these films are polycrystalline and not single-crystalline. Therefore, a research



team set out to find a method for synthesizing single-crystalline hBN films on a small scale.

The synthesis method they developed consists of letting the thin hBN film self-assemble on top of a liquid gold substrate. Because of the surface tension of liquid gold and the characteristics of its interaction with boron and nitrogen, circular hBN grains form automatically over time. These grains grow to a specific diameter and eventually form a lattice. They can easily rotate when they are about to come into contact with another grain so as to assume the best possible orientation before joining the lattice.

The final product of this process is

a nearly perfect single-crystalline hBN film, as demonstrated in many different experiments and via multiple measurements. A very promising application of such films is using them as a substrate for synthesizing other crystalline thin-film materials on top of them, such as graphene. Their

applications go beyond that.

"We demonstrated that our hBN films can serve as a protecting layer against metal oxidation and as a gas-diffusion barrier for water vapor transmission," Kim says.

This innovative synthesis method could be exploited further as well. "Our strategy for the synthesis of single-crystalline hBN films opens a new horizon for the single-crystal growth of other diatomic 2D materials," adds Kim. This would make many single-crystalline materials easier to fabricate, allowing them to naturally find a multitude of applications.

<http://science.sciencemag.org/content/362/6416/817>

[www.dongguk.edu/mbs/en/index.jsp](http://www.dongguk.edu/mbs/en/index.jsp)

## Mitsubishi develops ultra-wideband digitally controlled GaN amplifier for mobile base stations

Tokyo-based Mitsubishi Electric Corp has developed the first ultra-wideband digitally controlled gallium nitride (GaN) amplifier, which is compatible with a range of sub-6GHz bands focused on fifth-generation (5G) mobile communication systems.

The new ultra-wideband digitally controlled GaN amplifier uses an advanced load modulation circuit

with two parallel GaN transistors. The circuit expands the bandwidth of load modulation, a key factor for the amplifier's high efficiency, for wideband (1.4–4.8GHz) operation. The wide-band operation supports several frequency bands.

Digitally controlled input signals for the amplifier realize high-efficiency load modulation of above 40% over 110% of the fractional

bandwidth. Digital control employs learning functions based on Maisart (Mitsubishi Electric's AI creates the State-of-the-ART in technology).

With a power efficiency rating of over 40%, the amplifier can help to reduce power consumption in mobile base stations, contributing to large-capacity communications.

[www.MitsubishiElectric.com/semiconductors](http://www.MitsubishiElectric.com/semiconductors)

## NI AWR releases V14.02 Design Environment software

RF/microwave electronic design automation (EDA) software provider NI (formerly AWR Corp) of El Segundo, CA, USA says that an update to V14 of its Design Environment platform has been released and is now available to download for current customers and evaluators.

The v14.02 update contains numerous improvements, enhancements and upgrades. Highlights of the latest release include:

### User interface:

- API — The application programming interface (API) has been enhanced with numerous upgrades to access design editor information and control.

### Layout:

- Cell Libraries — New additions to the cell libraries provide a more robust implementation.
- Shape Preprocessing —

The unique geometry simplification rules that reshape circles and arcs can now increase as well as decrease the number of definition points.

- Visualization — The layout rendering performance for large designs has been improved, along with numerous other layout improvements.

### Simulators:

- Analyst — Several improvements have been made to the solver, most importantly, the intrinsic wave impedance in the solver options is now available as the wave port characteristic impedance method.
- Microwave Office/APLAC — Several key new functionalities have been added or enhanced to the APLAC harmonic balance (HB) simulator, including element

parameters can be swept as a function of frequency.

- AXIEM — The accuracy of the Green's function has been enhanced, and hence the moment matrix, resulting in improved convergence of iterative solvers for PCB, for example.

- Visuals System Simulator (VSS) — Both the capabilities and robustness of system simulation and behavioral models have been enhanced.

### Wizards:

- Innovative new wizards introduced in V14, namely the Printed-Circuit Board (PCB) Import wizard, the Phased-Array Generator wizard, and the Network Synthesis wizard, have been further enhanced, in response to customer feedback.

[www.awrcorp.com/products](http://www.awrcorp.com/products)

## Silvaco opens Shenzhen office to support Asian expansion and growing demand for design solutions

Silvaco Inc of Santa Clara, CA, USA (which provides electronic design automation and IP software tools for process and device development) has opened its latest China office to accommodate its continuing growth and reinforce its well-established sales, service and technical support for customers in China. Located at Suite 701, Building 6, Shenzhen Bay Science and Technology Park Zone 2, Shenzhen, Guangdong Province, the newest Silvaco China office includes both sales and applications engineering services.

"China is a key part of the global semiconductor ecosystem, with development in display, power IC, artificial intelligence (AI) and the Internet of Things (IoT), which are critical to the expansion of mobile and big-data electronics businesses," says Silvaco China's general manager Sharon Fang.

"Silvaco has been inside China since 2013, and our Shenzhen office is in a brilliant new commercial district where over 500 semiconductor technology, foundry and advanced electronics companies have established their manufac-

turing and R&D facilities," she adds. "Silvaco's EDA design tools and IP are positioned and delivering to this innovative new customer base, making China one of our fastest-growing regions," Fang continues. "The new center in Shenzhen strengthens our commitment to the expanding semiconductor IC market and our customers, who will now have even easier access to Silvaco's leading technological solutions and quicker support from our local sales and technical teams."

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## Leti and Silvaco to develop gate-all-around SPICE compact models for designing circuits using nanowire and nanosheet technologies

At the IEEE's 64th International Electron Devices Meeting (IEDM 2018) in San Francisco, CA, USA (1–5 December), micro/nanotechnology R&D center CEA-Leti of Grenoble, France and Silvaco Inc of Santa Clara, CA, USA (which provides electronic design automation and IP software tools for process and device development) have announced a three-year project to create unified SPICE compact models for the design of circuits using nanowire and nanosheet technologies.

The new predictive and physical compact model under development, Leti-NSP, builds on Leti's 15 years of model development, including the Leti-UTSOI model for FD-SOI (fully depleted silicon-on-insulator) technology. The Leti-NSP compact model uses a novel methodology for the calculation of the surface potential, including quantum confinement. It can handle arbitrary cross-section shapes of stacked planar and vertical gate-all-around (GAA) MOSFETs (circular, square, rectangular) and provides a tool for exploring the design of nanowire and nanosheet device architectures.

The collaboration will make the new device models available to designers through SmartSpice, Silvaco's high-performance parallel SPICE simulator for use by circuit designers. The corresponding model-parameters extraction flow will be implemented in Utmost IV, Silvaco's database-driven environment for characterizing semiconductor devices, to ensure an accurate fit between simulated and measured device characteristics.

Accuracy of analysis at the nanometer scale is essential for co-optimization of silicon process technology and circuit performance. Besides accurate device characteri-

zation and simulation, a complete solution includes TCAD (technology computer-aided design) simulation, and 3D parasitic extraction. Silvaco says that its partnership with leading research institutions for atomistic TCAD, and its proven in-house extraction solver technology, will provide an accurate design technology co-optimization (DTCO) solution for nanometer technologies.

"Over two decades, CEA-Leti and Silvaco have collaborated on design-technology co-optimization, ranging from innovative TCAD simulation to the design of advanced nanoelectronics, and thus expanded and strengthened Silvaco's suite of tools for designers," says CEA-Leti's CEO Emmanuel Sabonnadière. "This project continues that partnership, and when these physics-based compact models are made available to designers worldwide, they will be able to evaluate the potential of advanced nanowire-based CMOS technologies under development at CEA-Leti," he adds.

"DTCO, including circuit simulation, is fundamental to the development of electronic devices, and shrinking silicon geometries are placing an even greater premium on accuracy to capture and evaluate all the new physical effects in nanometer design," notes Eric Guichard, VP of Silvaco's TCAD Division. "Building on past successes of Leti and Silvaco's collaboration, this project will provide circuit designers and technologists with powerful, advanced design flows that combine CEA-Leti's physical, predictive, and easy-to-use models with Silvaco's high-accuracy EDA tools."

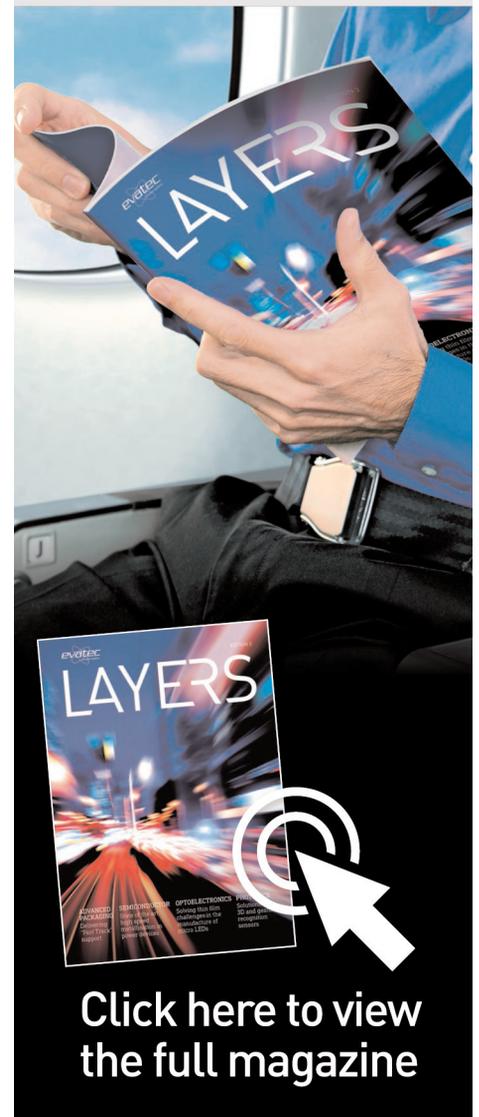
[www.ieee-iedm.org](http://www.ieee-iedm.org)

[www.silvaco.com](http://www.silvaco.com)

[www.leti.fr](http://www.leti.fr)



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## Disco completes construction of new Zone C in Kuwabata Plant's A-Building

Tokyo-based equipment maker DISCO Corp — which makes semiconductor manufacturing equipment including chemical mechanical polishing (CMP) systems and laser-based ingot slicing equipment and processes for silicon carbide (SiC) — says that, at the end of January, construction was completed on a new building (Zone C, A-Building) with a seismically isolated structure at its Kuwabata Plant in Kure City, Hiroshima, where precision processing equipment (for cutting, grinding and polishing wafers, etc) and tools (consumables) are manufactured. As a result, the floor space in the existing building (Zones A and B, A-Building) has been expanded (by about 65,900m<sup>2</sup> from 128,500m<sup>2</sup>), and production space will be increased by about 1.5 times. Construction began in

February 2017 and, after investing a total of JPY13.8bn in the expansion, operation will begin in February.

Semiconductor and electronic component markets are expected to continue expanding in the future based on the development of the Internet of Things (IoT), artificial intelligence (AI), self-driving technologies, and the installation of multiple cameras in smartphones. DISCO expects demand for its precision processing equipment and tools to increase accordingly.

DISCO has two production sites in Kure City, Hiroshima: Kuwabata Plant (mainly precision processing equipment) and Kure Plant (mainly precision processing tools). By allocating part of the production space in Kuwabata Plant's Zone B (for which construction was completed in January 2015) to precision pro-

cessing tools, a second production site was established to improve BCM (business continuity management) support. Moreover, by making the newly completed Zone C in Kuwabata Plant's A-Building a production space for precision processing tools, DISCO says it will further enhance the production system and BCM support, as well as making production more effective through the promotion of automation.

Disco adds that following the completion of Zone C, in order to respond to expected future increases in demand, between September 2019 and August 2021 JPY14bn will be invested in Kuwabata Plant's A-Building to construct Zone D, comprising a seismically isolated structure with floor space of about 67,400m<sup>2</sup>.

[www.disco.co.jp](http://www.disco.co.jp)

## Linton offers Kayex Intelligent Crystal Control System legacy console retrofit

Linton Crystal Technologies (LCT) of Rochester, NY, USA — which design and makes equipment for producing monocrystalline ingots of silicon as well as materials such as germanium and gallium arsenide for the semiconductor and solar industries — is offering a hardware retrofit for older Czochralski (CZ) process crystal growers that rely on MS-DOS-based control software (i.e. growers made by LCT prior to 2009).

The KICCS Legacy Console Retrofit provides up-to-date hardware and software process control and enables customers to take advantage of recent updates, as well as be supported through future improvements. The retrofit is customized to each customer's grower hardware and processes and can be completed on-site by the customer or an LCT technician with minimal downtime.

"Since we introduced our Kayex Intelligent Crystal Control System

(KICCS) in 2009, we stopped supporting the MS-DOS-based software that preceded it," says software and controls manager Brian Repman. "The computers that ran the older software also have since been discontinued, rendering the whole console obsolete," he adds. "The retrofit enables customers to replace the outdated console software with one that has many improved features, such as the ability to translate the interface into their native language."

The retrofit will allow customers to take advantage of the software features standard to more recent growers. This includes the integration of a KrystalVision camera into the console computer, with the ability to display the image on either of two screens. The retrofit also entails replacing any existing two-camera head unit with a single, high-resolution camera to reduce operator

setup and adjustment.

This higher resolution also provides the opportunity to perform more advanced functionalities within KrystalVision in the future, such as the melt gap software feature expected to be released early in 2019.

LCT's Web Integrated Grower Supervisor (WINGS), for remote furnace management and data collection, also runs on the retrofit and data can be maintained within a company's network for simultaneous, consistent data sharing across growers.

Additionally, legacy keyboard ports are replaced with USB keyboard ports, and additional USB ports are installed to allow for more convenient updates and file backup.

The computers are fan-less, powered from DC-voltage in the console, and support USB Flash disks and USB CD-ROM.

[www.lintoncrystal.com](http://www.lintoncrystal.com)

## US federal probe into alleged theft of AKHAN's IP by Huawei

AKHAN Semiconductor Inc of Gurnee, IL, USA — founded in 2013 for the fabrication and application of lab-grown, electronics-grade diamond as functional semiconductors — recently cooperated with a US federal investigation into what appears to be a theft of its intellectual property by Huawei Technologies Co Ltd.

AKHAN says that, when it sent its proprietary Miraj Diamond technology to Huawei pursuant to an agreement, it expected that Huawei would abide by the agreement and that its material would be returned unharmed. Unfortunately, AKHAN believes that Huawei destroyed its product, shipped it to China without authorization, subjected it to tests that it was not authorized to conduct, and returned most of the product in pieces. AKHAN

still has not recovered all of it from Huawei, despite repeated written and oral requests and inquiries.

AKHAN says that it takes seriously any unlawful use of its technology, and that theft of assets, attempted or successful, will be not be tolerated. It will continue to cooperate with law enforcement and work towards an expedient resolution. Given the threat that the apparent theft poses to its shareholders, employees and customers — and the potential loss to US jobs, revenue and other projected economic impact — AKHAN is considering all legal remedies available, and will work with the involved parties to make public any relevant information to stakeholders.

[www.akhansemi.com](http://www.akhansemi.com)

## EpiGaN in 2019 Cleantech 100 list

At the 17th annual Cleantech Forum San Francisco, EpiGaN nv of Hasselt, Belgium — which supplies gallium nitride on silicon (GaN-on-Si) and gallium nitride on silicon carbide (GaN-on-SiC) epitaxial wafers for power switching, RF and sensor applications — is again included by the Cleantech Group (CTG) in its annual Global Cleantech 100 list.

Featuring independent, for-profit companies best positioned to solve future clean technology challenges, Global Cleantech 100 lists firms with the highest potential market impact. It combines proprietary CTG research data with qualitative judgments from an 87-person expert panel.

Incorporated in 2010, EpiGaN was founded by chief executive officer Dr Marianne Germain, chief technology officer Dr Joff Derluyn and chief operating officer Dr Stefan Degroote as a spin-off of nanoelectronics research center Imec of Leuven, Belgium, where they jointly developed GaN-on-Si technology (part of which has been licensed to EpiGaN). EpiGaN was joined in 2011 by start-

up investment firms Robert Bosch Venture Capital, Capricorn CleanTech Fund and LRM (to enable the installation of its wafer production facility) and in August 2016 by ACAPITAL.

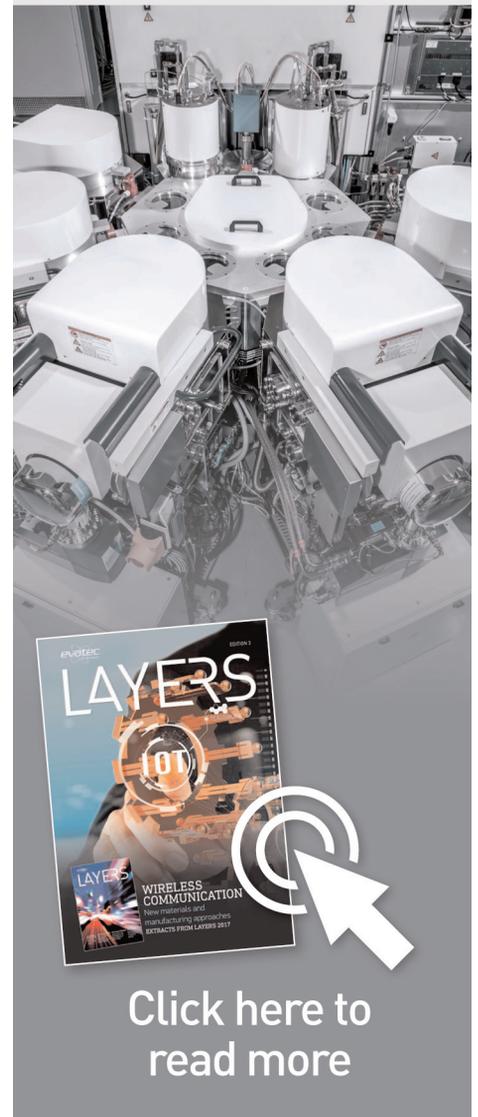
"Innovative GaN technology enables drastic energy savings, volume and weight reductions of power systems, miniaturization and significant cost reduction in areas where traditional silicon solutions cannot meet current or future system requirements," says Germain. "EpiGaN offers unique and state-of-the-art solutions addressing the demanding mm-wave specifications for 5G cellular networks. EpiGaN's product portfolio also covers sensor applications," she adds. "At our production facility in Hasselt (Belgium), we have developed unique GaN-on-Si and GaN-on-SiC wafer technologies up to 200mm on Si, and 150mm on SiC... This year we are significantly scaling up our production capacity to meet the increasing demand."

[www.epigan.com](http://www.epigan.com)

[www.i3connect.com/gct100/the-list](http://www.i3connect.com/gct100/the-list)



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# Newport compound semiconductor foundry at CScnected recruits first 32 staff

## First ten production tools installed, with capacity in place for next ten; first product samples already shipped

Epiwafer foundry and substrate maker IQE plc of Cardiff, Wales, UK says that, within the first year of the compound semiconductor wafer foundry in Newport, South Wales, 32 technicians and engineers have begun work, with a further 10 vacancies in the process of being filled.

Secured by the Cardiff Capital Region (CCR) City Deal's Wider Investment Fund for £38.5m and leased by IQE for compound semiconductor manufacturing and applications development, the facility will become the hub of the regional technology cluster CScnected (the world's first compound semiconductor cluster), based in South Wales.

Since the signing in September 2017, IQE has accelerated its expansion plans at the new flagship site, recruiting and training for the first 32 new roles within the first 12 months, with many more to follow. More than 75% of the roles had been recruited within the Cardiff Capital Region, coming from eight of ten council areas represented within the City Deal.

"This investment is already generating significant, good quality employment that will strengthen the wider region and some of its most deprived areas," says CCR director Kellie Beirne. "Compound semiconductor technologies represent a thriving sector that will support many youngsters within our region and boost their skills. It's encouraging to see this innovative sector flourish in the heart of our region," she adds.

"The creation of the world's first compound semiconductor cluster in South-East Wales is exactly the kind of investment we are seeking to achieve for this region," says Councillor Peter Fox, leader of Monmouthshire County Council and co-lead for Business and Innovation.



**IQE's CEO Drew Nelson with the first staff recruits at the new Newport-based compound semiconductor foundry.**

With construction at the new facility in full force and the first phase completed, the investment has also provided employment opportunities for construction firms based in the region: 20% of all the construction staff came from organizations based in Rhondda Cynon Taf.

"Our vision is to create the world's first end-to-end compound semiconductor cluster in South Wales, and in doing so set the foundations for many high-tech supply chains to all major industrial sectors globally," says IQE's CEO Dr Drew Nelson.

"Growing global demand for compound semiconductor-enabled technologies has led to our significant investment in capital and people. When fully operational, we expect to employ up to 500 people at the Newport facility," he adds.

"Throughout its first year, the Newport semiconductor site has provided employment for an average of 84 construction workers every week. Around three quarters of that work has gone to firms either based, or with an office in, the Cardiff Capital Region, supporting regional workforces."

With facilities at the flagship site in place, the first ten production tools have been installed, with capacity in place for the next ten. The first product samples have already shipped from the foundry

site.

A £50m investment in the Compound Semiconductor Applications Catapult by Innovate UK has also been confirmed as part of the CScnected cluster, which will bring with it

about 90 jobs and support R&D across the compound semiconductor sector. Work will begin on installing the Catapult facility in the coming weeks.

Also, the Cardiff University-led Centre for Doctoral Training (CDT) in Compound Semiconductor Manufacturing will provide PhD-level training aligned with the needs of UK industry. It is one of 75 CDTs announced by the UK Engineering and Physical Sciences Research Council (EPSRC) as part of a £446m investment in skills by UK Research and Innovation (UKRI).

Co-created with IQE, Compound Semiconductor Centre, Newport Wafer Fab and the Compound Semiconductor Applications (CSA) Catapult, the CDT is an alliance of four universities (Cardiff, UCL, Sheffield and Manchester) and 24 companies, many already working closely together via the EPSRC Future CS Manufacturing Hub, based at Cardiff University. With established excellence in CS disciplines, the CDT aims to provide distinctive PhD training that is industrially relevant and intellectually challenging.

[www.newportwaferfab.co.uk](http://www.newportwaferfab.co.uk)

[www.iqep.com](http://www.iqep.com)

[www.compoundsemiconductorhub.org](http://www.compoundsemiconductorhub.org)

<http://csconnected.com>

# CEA-Leti extends 300mm wafer line to open new R&D avenues for industrial partners

## Memory, photonics, power electronics, 3D and quantum technology targeted

At the IEEE's 64th International Electron Devices Meeting (IEDM 2018) in San Francisco, CA, USA (1–5 December), micro/nanotechnology R&D center CEA-Leti of Grenoble, France announced an extension of its 300mm silicon-based wafer line to open new R&D avenues for its industrial partners. The extension will allow new technological modules to be inserted in, or made compatible with, industrial flows up to completely pioneered technology routes that enable edge-AI (artificial intelligence) and high-performance computing (HPC) in memory, photonics, power electronics and other high-end applications.

CEA-Leti's 300mm wafer-line extension aims to accelerate innovation projects with fab partners using 300mm wafers. Targeted technological routes and related applications include:

β memory: phase-change RAM (PCRAM), oxide-based resistive memory (OxRAM) and conductive-bridging RAM (CBRAM);

- vertical image sensors;
- photonics: III-V on silicon, integrated photonics;
- power electronics: insulated-gate bipolar transistors (IGBTs);
- HPC and edge AI: FD-SOI (fully depleted silicon-on-insulator) and derivatives, such as sequential stacking and Si qubits for quantum computing;
- 3D wafer-to-wafer or die-to-wafer bonding, hybrid bonding: substrates and layer transfer for advanced substrates in collaboration with Soitec.

CEA-Leti's advanced CMOS strategy targets FD-SOI research through the development of modules to the economic and technological limits of scaling, and complements the extension of the

300mm platform for edge-AI applications, analog applications, RF and power electronics.

The strategy is based on a mix of priorities of CEA-Leti's partners and its researchers' ideas that pioneer enabling technologies to address societal challenges. These include cloud and edge computation, high-volume communication, multi-modality interaction and energy conservation. Leti says it is executing the strategy with its fully implemented technology, from beginning to end with module-level innovations, such as insulation or back-end copper, as well as devices and their architectures.

"Our 300mm line will help Leti continue this strategy by accessing dimensions that make it possible to address the pressing challenges associated with emerging technologies, such as quantum, nanowires and sequential 3D integration," says CEA-Leti's CEO Emmanuel Sabonnadière. "CEA-Leti's industrial partners are now able to develop or test their disruptive technologies and their designs on state-of-the-art equipment, while benefiting from the institute's R&D expertise, to achieve improved component performance, direct comparison with the ecosystem and easier technology transfers from lab to fab."

Implementation of the 300mm line is enabled by the Auvergne Rhone Alpes region financing the acquisition of a 193nm-wavelength immersion lithography tool, which is the cornerstone of the investment plan (2017–2018). CEA-Leti has also benefited from financial support from the French government for the second phase of the plan (2018–2019).

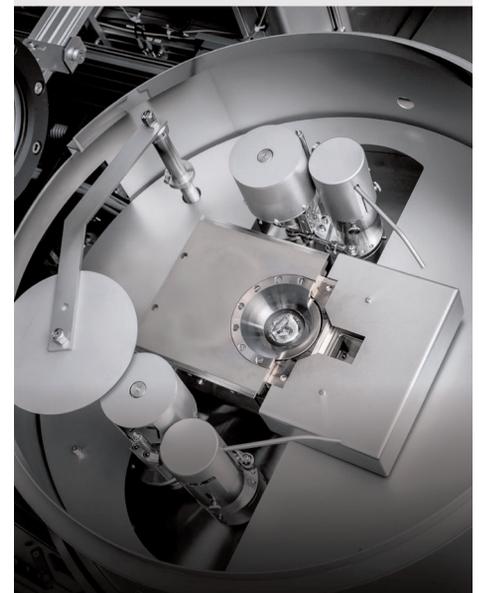
[www.ieee-iedm.org](http://www.ieee-iedm.org)

[www.leti.fr](http://www.leti.fr)



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# AXT's revenue falls 22.4% in Q4/2018, due partly to weak China LED market

## Full-year growth aided by InP sales as silicon photonics takes off

For full-year 2018, AXT Inc of Fremont, CA, USA — which makes gallium arsenide (GaAs), indium phosphide (InP) and germanium (Ge) substrates and raw materials — has reported full-year revenue growth of 3.7% from \$98.7m in 2017 to \$102.4m in 2018, aided by another record for InP sales as silicon photonics passed the tipping point of broader market adoption.

However, for fourth-quarter 2018 revenue is just \$22.2m, down 22.4% on \$28.6m last quarter (and well below the original guidance of \$26.5–27.5m).

In particular, substrate sales were \$17.2m, down 25% on \$22.8m. Revenue from raw material joint ventures (namely the three firms consolidated into AXT's results) was \$5m, down 13.8% on \$5.8m.

Of total revenue, 69% came from Asia Pacific (down from 72%), 10% from North America (down slightly from 11%), and 21% from Europe (up from 17%). One customer comprised 10% of total revenue and the top five generated about 35% (down from 39%, showing diversification of the customer base).

"Coming off of a strong Q3, we entered Q4 with the understanding that our customers across our portfolio were cautious regarding Q4 requirements," says CEO Morris Young. "This shortfall was a combination of trade tension, weakness in the LED market (particularly in China and for applications such as automotive), a slowdown in growth in data-center market, as well as inventory rebalancing at several of our large customers and the natural lumpiness of revenue from emerging applications for our gallium arsenide product," he adds.

"Global economic conditions were made more difficult by the uncertainty of trade tensions, and spending in certain end markets took a pause, impacting our expected

growth and profitability for the year," he adds.

Full-year gross margin has risen from 34.9% in 2017 to 36.2% in 2018. However, quarterly gross margin has fallen from 37.1% last quarter to 26.3% in Q4/2018. This was due to (1) lower revenue (and hence greater overhead costs per unit sold); (2) increased manufacturing overheads after hiring and training new staff and accruing other costs from relocating GaAs and Ge manufacturing from Beijing to Dingxing, China; and (3) a sharp rise in raw materials costs (especially germanium) in late Q3 and Q4.

Operating expenses have grown further, from \$6.1m a year ago and \$6.3m last quarter to \$6.5m, driving full-year OpEx up from \$21.8m in 2017 to \$24.9m in 2018.

Net income has fallen from \$10.1m (\$0.26 per diluted share) in full-year 2017 to \$9.7m (\$0.24 per diluted share) in full-year 2018. Specifically, quarterly net income has gone from \$3.1m (\$0.08 per diluted share) a year ago and \$3.9m (\$0.10 per diluted share) last quarter to a net loss of \$1.1m (\$0.03 per share) in Q4/2018.

Depreciation and amortization was \$1.4m. Capital expenditure (CapEx) was \$11m. Due mainly to the new facility and equipment, cash, cash equivalents and investments hence fell during the quarter from \$42m to \$39m.

After previous increases in net inventory due to the ramp-up of AXT's new GaAs and Ge manufacturing manufacturing facilities in Dingxing, net inventory fell slightly during the quarter from \$58.7m to \$58.6m, of which raw materials fell from 51% to 46% while work in progress rose from 44% to 48% and finished goods from 5% to 6%. "We did let inventory grow on the front end of the relocation program and then we slowed that down last

spring and inventory has been relatively flat since 30 June 2018," says VP & chief financial officer Gary Fischer. "We have made the reduction in inventory a focus for our team in China. We will begin to see more meaningful results over the coming quarters. With the programs we have in place, we would expect to be able to drive it below \$50m and perhaps a bit more over the coming year," he adds.

"We do not expect business conditions to improve meaningfully in the first quarter," comments Fischer. "The markets and geographies that were weak in Q4 will remain so throughout Q1, and the inventory correction at certain customers will also continue through Q1," says Young.

For Q1/2019, AXT expects revenue to fall further to \$20–21m, with loss per share rising to \$0.04–0.06.

"Although Q1/2019 is challenging, as we look ahead we are encouraged that the tone of customer comments includes an expectation for market recoveries later this year," notes Young. "Despite the challenges in 2018 we saw growth in a host of new gallium arsenide applications that further suggest this material is entering its next period of expansion," he adds. "In our current discussion with customers, sentiment is improving for 2019 demand in all of our key applications that drive our business."

Regarding gross margin, Fischer believes that AXT can get it back to the previous ranges (of the first two quarters of 2018). "The timing will depend on the recovery in the markets we serve, as an increase in revenue will be a primary driver for the improvement. In addition, we are also implementing programs to improve yields and stabilize and optimize the efficiencies of multiple manufacturing sites. These are expected to contribute to an

improvement over the next couple of quarters," he adds.

"Our competitive position remains strong," believes Young. "This will enable us to return to growth when the markets recover. In the meantime, we intend to continue the relocation [from Beijing], strengthen our business and drive greater efficiencies in our model," he adds. At least 90% of AXT's GaAs and Ge production capability

should be established in the new Dingxing facility by the end of Q2/2019. "This positions us well for new and recovering gallium arsenide business opportunities. In addition, we are now well underway with current customer qualifications, including all of our major customers," says Young.

"Our primary expenditure will be focused on the completion of the facility [in Dingxing], for which we

expect to spend about \$21m over the course of 2019," says Fischer. "Some of this cost will be offset in our cash balance by our reduction in inventory, as well as our expectation of returning to positive operating cash flow in the second half of 2019. Also, the current facility in Beijing has considerable value that we will be able to monetize in the future."

[www.axt.com](http://www.axt.com)

## 5N Plus secures new US\$25m unsecured term loan

Specialty metal and chemical products firm 5N Plus Inc of Montreal, Québec, Canada has closed a US\$25m unsecured subordinated term loan with Investissement Québec.

5N Plus provides purified metals such as bismuth, gallium, germanium, indium, selenium and tellurium, and also produces related II-VI semiconducting compounds such as cadmium telluride (CdTe), cadmium sulphide (CdS) and indium antimonide (InSb) as precursors for the growth of crystals for solar, LED and eco-friendly materials applications.

Launched in 2016, the company's strategic plan 5N21 identified the specialty semiconductor sector as a key growth area, aiming to grow the revenue contribution from this sector to 15% of total revenue by 2021. This investment should be completed by mid-2019 and is included in the overall investment envelope envisioned under 5N21 which aims to deliver adjusted EBITDA of US\$45m along with 17%

return on capital employed by 2021.

The firm says that, since the launch of 5N21, it has been delivering results in line with the defined targets. During this time, 5N Plus has continued to undergo a transformation that is taking it from manufacturing and sales of specialty metals and chemicals to that of engineered materials, yielding margin expansion and improved return on capital employed.

As 5N Plus nears the half-way point of its strategic plan, it is expected that more emphasis will be placed on the development of its growth initiatives along with further investment in efficiency gains from its core businesses. It is hence expected that proceeds from the unsecured term loan will be used to support these programs along with repayment of the balance of the unsecured convertible debentures issued by the firm in 2014; which will mature on 30 June. The new loan has a five-year term and will be disbursed in two tranches: the

first of US\$5m on 6 February and a second of US\$20m by no later than 29 March. The new term loan will bear interest equivalent to the 5-year US dollar swap rate plus a margin of 4.19% (which currently equates to about 6.80%).

"The new term loan and our recently renewed senior revolving credit facility constitute a well-balanced portfolio of financing," believes chief financial officer Richard Perron. "With this backbone, our company is ideally positioned to fund its future ambitions defined by 5N21 while addressing both flexibility and cost effectiveness," he adds. "The new financing structure avoids dilution potential for our shareholders, mainly as it pertains to convertible debt instruments," Perron continues "As we continue to transform our company and deliver tangible value, we are elated to have the support of Investissement Québec, an important institution in the local business community."

[www.5nplus.com](http://www.5nplus.com)

## 5N Plus shareholders approve reduction in stated capital

5N Plus says that, at a special meeting in Montreal, shareholders voted to approve the following resolution: "The stated capital of the common shares of 5N Plus be reduced to US\$5m and the amount of the reduction be added to the contributed surplus of the company".

"The reduction of stated capital will benefit the company on a go-forward basis by providing more flexibility in managing its capital structure, including its ability to pay dividends and repurchase common shares," says chief financial officer Richard Perron. "It will not result in any change to shareholder

equity as presented in the company's financial statements and therefore will not affect the company's book value," he adds. "The reduction of stated capital will also have no impact on the day-to-day operations of the company and will not, on its own, alter the financial condition of the company."

## Simgui enhances partnership with Soitec to double 200mm SOI wafer capacity from 180,000 to 360,000

Soitec of Bernin, near Grenoble, France, which makes engineered substrates including silicon-on-insulator (SOI) wafers, and Chinese silicon-based materials manufacturing partner Shanghai Simgui Technology Co Ltd (a provider of both customized SOI wafers and epiwafer foundry services) have jointly announced an enhanced partnership and a doubling of annual production capacity of 200mm SOI wafers from 180,000 to 360,000 at Simgui's manufacturing facility in Shanghai to better serve the growing global market for RF-SOI in mobile and power-SOI products.

Since signing their original licensing and technology transfer agreement in May 2014, Simgui has used Soitec's proprietary Smart Cut process to deliver RF-SOI and power-SOI products. The strategic partnership allows Simgui to use the same tools and processes to deliver the same products meeting the same specifications.

The firms say that the ramp up in production is a direct result of their close collaboration and customer focus to deliver SOI products at high volume. To further advance this aim, they have redefined their original financial agreement and specific roles regarding the 200mm wafers produced by Simgui. Simgui will focus on SOI wafer manufacturing and Soitec will manage worldwide product resale. To meet increasing worldwide demand for 200mm SOI in response to the growing market for RF-SOI used in mobile front-end modules (FEM) and for power-SOI used in automotive and consumer electronics, Simgui has invested in its Shanghai fabrication line to offer increased production capacity. The fab is production ready, having been qualified by multiple key customers both inside and outside China.

"We are very pleased to continue our long-standing history and

manufacturing partnership with Simgui to secure 200mm capacity for our customers in markets where RF-SOI is today a standard for RF FEM for 4G & 5G and power-SOI shows strong growth," says Dr Bernard Aspar, Soitec's executive VP, Communications and Power business unit. "Soitec and Simgui are committed to serve this industry with the right level of capacity and product quality," he adds.

"Through our industrial collaboration with Soitec, Simgui has proven the robustness and high-volume scalability of Soitec's Smart Cut technology," says Simgui's CEO Dr Jeffrey Wang. "China has design, wafer manufacturing and good momentum in the IC industry," he adds. "We are committed to our strategic partnership with Soitec to keep advancing SOI as China's key differentiator."

[www.simgui.com.cn/en](http://www.simgui.com.cn/en)  
[www.soitec.com](http://www.soitec.com)

## Riber grows annual revenue by 2.3% to a record €31.3m

For fourth-quarter 2018, Riber S.A. of Bezons, France — which manufactures molecular beam epitaxy (MBE) systems as well as evaporation sources and effusion cells — has reported revenue of €9.7m, almost doubling from €4.9m in Q3 and exceeding the €9.5m in Q2.

Full-year 2018 revenue was €31.3m, up 2.3% from 2017's €30.6m (which was a historically high year, with growth of 86% versus 2016). Europe contributed 49% of revenue (up from 33% in 2017), Asia 43% (down from 49%) and North America 8% (down from 18%).

Revenue for MBE systems was

€9.6m (six systems, including three production units), up 33% on 2017's €7.2m (five systems, including two production units), despite the deferral of deliveries for two systems (to be invoiced in first-quarter 2019, as indicated on 10 January).

Revenues for services & accessories were €10.1m, up 12% on 2017's €9m, reflecting the drive to regularly develop this business (which contributes strongly to gross margin).

Revenues for evaporators (cells and sources) were €11.6m, down 19% on 2017's €14.4m, maintaining a high level, focused mainly on an Asian client.

The order book has risen by 16% from €25.8m at the end of 2017 to €29.9m at the end of 2018.

Systems order are up 83% from €12.2 to €22.3m, including 13 MBE systems (of which seven are production machines).

Services & accessories orders are down 22% from €8.7m to €6.8m (a temporary decline, says Riber).

Evaporators orders are down 84% from €4.9m to €0.8m, related to a temporary slowdown in investments in screen production lines.

Due to the large order book, to be invoiced over 2019, Riber forecasts a further year of revenue growth.

## Asian firm orders second MBE 6000 multi-wafer production system

An industrial firm in Asia has ordered a second Riber MBE 6000 multi-wafer production system, to

produce optoelectronics components for the fiber-optic interconnection markets.

Riber says this second order confirms the relevance of the decision to open its Asian subsidiary in 2018.



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# Veeco's revenue falls 22% in Q4/2018 due to commoditization of China LED MOCVD market

## Focus on transition to Front-End Semiconductor and Compound Semiconductor markets such as MOCVD for 3D sensing VCSELs

Epitaxial deposition and process equipment maker Veeco Instruments Inc of Plainview, NY, USA has reported full-year revenue of \$542.1m for 2018, up 14% on \$475.7m for 2017.

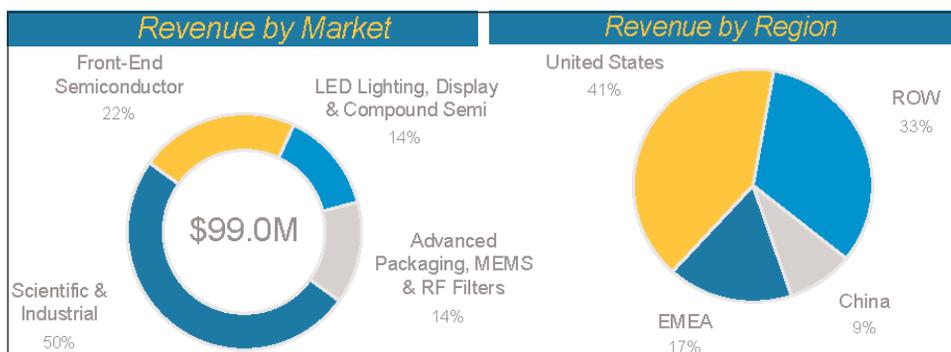
However, this was despite fourth-quarter revenue of just \$99m, falling by 21.9% from \$126.8m last quarter and 29.1% from \$139.7m a year ago.

The LED Lighting, Display & Compound Semiconductor segment plummeted from 46% of total revenue last quarter to just 14%.

"The commodity portion of the LED business, which includes the sale of our MOCVD [metal-organic chemical vapor deposition] systems to the China LED market, has been under pricing pressure and is becoming a smaller portion of our business," says CEO Bill Miller. Most of this segment's revenue was therefore in Compound Semiconductors, including MOCVD systems for specialty LEDs, automotive, photonics and power electronics applications as well as Precision Surface Processing (PSP) systems for RF device manufacturing.

The Advanced Packaging, MEMS & RF Filter segment - including lithography and PSP systems sold to integrated device manufacturers (IDMs) and outsourced assembly & test firms (OSATs) for Advanced Packaging in automotive, memory and other areas - fell from 19% to 14% of total revenue, due to the continued low smartphone business environment.

The Front-End Semiconductor segment (formerly part of the Scientific & Industrial segment, before the May 2017 acquisition of lithography, laser-processing and inspection system maker Ultratech Inc of San Jose, CA, USA) rose from 11% to 22% of total revenue, driven by laser spike annealing (LSA) for foundry customers.



The Scientific & Industrial segment (including shipments to data storage and optical coding customers) grew sharply from 24% to 50% of total revenue, due to expansion by data storage customers to increase areal density and to respond to the growth in cloud storage.

Geographically, compared with last quarter, China has plummeted from 31% to just 9% of total revenue ("indicative of the revenue profile going forward", having been as much as 47% in Q2/2018). Europe, Middle East & Africa (EMEA) has fallen back from 24% to 17%. Meanwhile, the USA has risen sharply from 23% to 41%, and rest of the world from 22% to 33% (driven by Front-End Semiconductor shipments to Taiwan and Korea).

On a non-GAAP basis, gross margin has fallen further, from 40.5% a year ago and 38.2% last quarter to 36% (well below the prior goal of 40%), impacted negatively by low volumes but offset by benefits from product mix. Full-year gross margin has hence fallen from 39.7% for 2017 to 36.6% for 2018.

Full-year operating expenditure (OpEx) was \$175.2m, but quarterly OpEx has been cut from \$49m a year ago to \$42.6m in Q4, mainly through cutting selling, general & administrative (SG&A) spending rather than R&D spending for growth sectors.

Q4/2018 yielded a net loss of \$7.5m (\$0.16 per diluted share),

compared with net income of \$5.3m (\$0.11 per diluted share) last quarter and \$6m (\$0.13 per diluted share) a year ago. Full-year net income was hence down, from \$16.8m (\$0.38 per diluted share) for 2017 to \$14.2m (\$0.30 per diluted share) for 2018.

Cash flow from operations fell from \$18m last quarter to just \$2m in Q4. During the quarter, cash and short-term investments fell by \$5m from \$266m to \$261m.

Long-term debt on the balance sheet rose slightly from \$284m to \$287m, representing the carrying value of \$345m in convertible notes. There were no share repurchases in Q4/2018, but for the full year Veeco repurchased 950,000 shares (about 2% of its market capitalization) at an average price of \$11.88 per share.

Despite being down 37% on \$179m a year ago, order bookings of \$112m in Q4/2018 are up 12% on \$100m in Q3. "We see order activity in leading-edge Front-End Semiconductor and exciting growth opportunities in Compound Semiconductor and Advanced Packaging," notes Miller.

The Front-End Semiconductor market was steady at 36% of total bookings due to strong momentum in LSA products for foundry customers and at EUV mask blank customers. Advanced Packaging, MEMS & RF Filters orders rose from just 11% to 19% of overall bookings. LED Lighting Display and

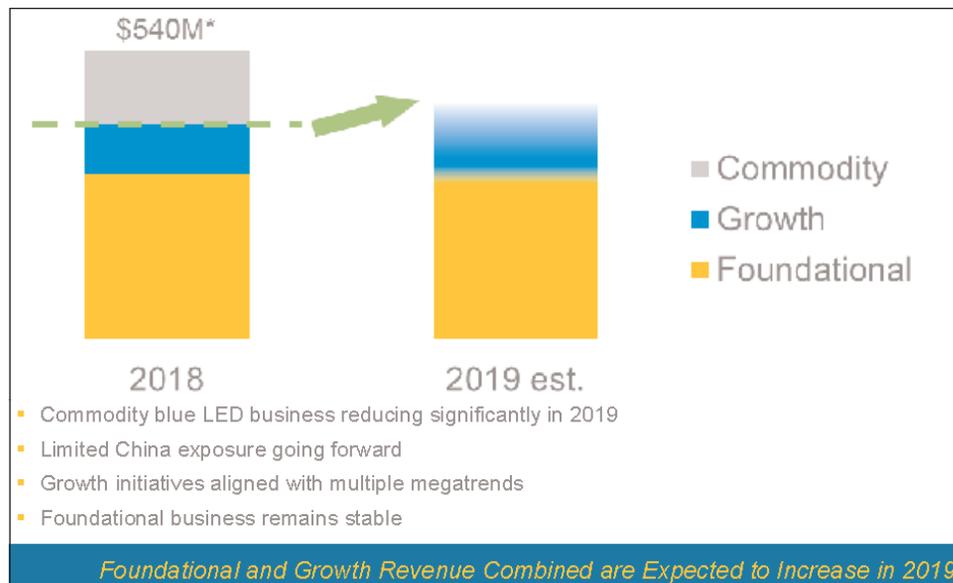
Compound Semiconductor orders remained just 12% of bookings due to the reduced levels of commodity blue LED business (especially from China). Scientific & Industrial orders fell from 39% to 33% of overall bookings.

Order backlog rebounded slightly from \$276m last quarter to \$288m in Q4 (though still down on \$334m a year ago).

Veeco says that its foundational businesses remain stable and include: service business; wet etch & clean; data storage; universities & research labs; and optical coatings for industrial, medical & military markets.

The cash generated by these foundational businesses is supporting the following growth initiatives (which align with multiple megatrends): ion beam deposition systems for EUV mask blanks and laser annealing for advanced wafer processing (Front-End Semiconductor); MOCVD (Compound Semiconductor) for 3D sensing/VCSELs (vertical-cavity surface-emitting lasers); and lithography for wafer-level packaging (Advanced Packaging).

As Veeco hence focuses on a business transition from commodity blue LED MOCVD markets to the Front-End Semiconductor and



Compound Semiconductor markets, inventory remains elevated (rising from \$150m in Q3 to \$156m in Q4) as it ramps EUV mask blank systems production and continues to invest in new products for MOCVD and to engage key customers with evaluation systems. Consequently, days of inventory (DOI) rose further, from 173 days in Q3 to 219 days in Q4.

For first-quarter 2019, Veeco expects roughly level revenue of \$85-105m and gross margin of 34-36%. Despite OpEx being cut further to \$41m, net loss should be \$14-5m (\$0.30-0.10 per share).

"Based on our backlog and current visibility, we see Q2 sales cracking slightly above Q1," says chief operating officer & chief financial officer Sam Maheshwari. "We are on track to meet our target of \$40m of OpEx for Q2/2019," he adds.

"As we look at 2019, we expect the combination of foundational and growth businesses to grow, while the commodity MOCVD business declines," says Maheshwari. "We currently expect 2019 revenue to be higher than the current quarterly revenue run rate would suggest [and likewise for gross margin]."

[www.veeco.com](http://www.veeco.com)

## Germany's AIM Infrarot-Module buys third Veeco GEN20 MBE system

AIM Infrarot-Module GmbH of Heilbronn, Germany, a manufacturer of infrared detectors and thermal sights, has purchased a third Veeco GEN20 automated molecular beam epitaxy (MBE) system, citing the outstanding performance and reliability of the system as the basis for AIM's decision.

Veeco says that AIM's prior GEN20 systems have delivered results that highlight the reliability of the MBE sources and performance of the substrate heater across demanding temperature and growth environments. In addition, Veeco's scientific support has helped AIM to create infrared detectors for research, industrial,

security and environmental protection applications.

The GEN20 is a flexible MBE system with a design configurable for mercury cadmium telluride (HgCdTe) devices, other II-VI compound semiconductors, and traditional III-V materials. A benefit is its cluster tool wafer transfer system, which is suitable for AIM's efforts to scale from lab to fab for short-wavelength infrared (SWIR) to long-wave infrared (LWIR) and especially multi-spectral technologies.

"The current demand for advancements in infrared detectors, along with challenges in the SWIR to LWIR, requires state-of-

the-art MBE technologies and performance," says Drew Hanser Ph.D., VP of technology for Veeco's compound semiconductor business unit. "AIM's decision to add to its existing portfolio of Veeco tools validates our team's commitment to superior product performance and dedication to helping our customers achieve their technology goals across a broad range of industries," he adds.

Veeco showcased its latest innovations in molecular beam epitaxy at the 20th European Workshop on Molecular Beam Epitaxy (EuroMBE 2019) in Lenggries, Germany (17-20 February).

[www.eurombe2019.com](http://www.eurombe2019.com)

## Brooks Instrument highlighting new pressure-based MFC at CSTIC and SEMICON China

Brooks Instrument of Hatfield, PA, USA, a provider of flow, pressure, vacuum and vapor delivery solutions, is showcasing its new GP200 Series pressure-based mass flow controller (P-MFC) at the China Semiconductor Technology International Conference (CSTIC 2019) in Shanghai (18–19 March) in conjunction with SEMICON China 2019 (20–22 March), where it is co-exhibiting in booth N33675 with its regional business partner SCH Electronics Co Ltd.

During the conference, chief technology officer Mohamed Saleem is discussing the GP200 P-MFC's design, operation and capabilities in a presentation 'A New Differential Pressure Sensor-based Mass Flow Controller for Advanced Semiconductor Processing'.

Designed with exclusive alarm capabilities for early detection of potential process issues, the GP200



Brooks Instrument's  
GP200 P-MFC

P-MFC enables precise and repeatable control for critical gas delivery applications and is fully pressure insensitive to dynamic inlet and outlet pressure conditions. Process gas accuracy is  $\pm 1\%$  and repeatability is  $\pm 0.15\%$  of set point.

Brooks Instrument developed the GP200 P-MFC based on a combination of absolute and differential pressure transducers, where a single differential pressure sensor is used instead of two absolute pressure sensors to compute pressure drop. "The advantage of this technique is that it eliminates the need for having matched absolute sensors, and therefore prevents uncontrolled drifts and flow inaccuracies, which yields superior accuracy and repeatability of flow measurement," says Saleem.

At SEMICON China, Brooks Instrument is also featuring the GF125 Series MFCs, the GF125 with high-speed EtherCAT, the GF100 Series high-flow MFCs and the VDM300 vapor delivery module, now with EtherCAT.

[www.brooksinstrument.com](http://www.brooksinstrument.com)

[www.semiconchina.org/en/5](http://www.semiconchina.org/en/5)

## Fraunhofer Institute for Telecommunications to receive Veeco's SPECTOR ion beam sputtering system with enhanced Sirius Optical Monitoring System

Veeco Instruments Inc of Plainview, NY, USA has shipped its SPECTOR Ion Beam Sputtering (IBS) system and Sirius Optical Monitor System (OMS) to Fraunhofer Institute for Telecommunications, Heinrich Hertz Institute (HHI), in Berlin, Germany, which will use IBS technology to develop and produce laser facet coatings and micro-optical devices.

"The development of sophisticated micro-optical devices requires exceptional sputtering technology," says Ms Greta Ropers, head of backend and packaging group for Fraunhofer. "Veeco's SPECTOR system, coupled with the Sirius OMS, ensures we are developing and producing world-class devices with the highest throughput and process repeatability on an automated, proven platform," she comments.

Veeco says that, according to cus-

tomers, the SPECTOR platform generates high-quality optical thin films with improved levels of productivity and throughput. Unlike evaporative coatings, ion-beam-sputtered thin films are deposited at high energies, giving exceptional thickness control and low defect densities for laser coating applications. The firm adds that its Sirius OMS significantly enhances the SPECTOR platform capability by coupling cutting-edge broadband monitoring control with the inherent stability of ion-beam-deposited films.

"Fraunhofer Institute for Telecommunications is a recognized worldwide leader in developing next-generation laser facet coatings and micro-optical devices," comments Adrian Devasahayam Ph.D., VP & general manager of Veeco's Advanced Deposition and Etch

(AD&E) business. "The SPECTOR system sets the standard for precision optical coating thin films by providing unparalleled quality and flexibility that will no doubt accelerate their development goals."

Funding for the project was granted by Forschungsfabrik Mikroelektronik, a cross-location research factory for microelectronics and nanoelectronics consisting of 11 institutes within the Fraunhofer Group along with IHP GmbH - Innovations for High Performance Microelectronics and the Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik.

The system was sold in cooperation with Veeco's European channel partner veonis Technologies GmbH.

[www.forschungsfabrik-mikroelektronik.de/en.html](http://www.forschungsfabrik-mikroelektronik.de/en.html)

[www.veeco.com](http://www.veeco.com)

# LayTec launches EpiX modular wafer mapping station for compound semiconductor research

In-situ metrology system maker LayTec AG of Berlin, Germany has launched the EpiX wafer mapping station for compound semiconductor R&D.

Currently, there is an ongoing boom in metal-organic chemical vapor deposition (MOCVD)-grown III-V lasers, with a corresponding resurgence in related material research, notes the firm. LayTec already supports this with in-situ metrology products such as EpiTT VCSEL or EpiTT FaceT, and EpiX is the next new product. The first EpiX station was installed at a customer site in mid-2018, and combines white light reflectance with photoluminescence (PL) measurements, allowing comprehensive 2D analysis over a wide spectral range (400–1700nm).

Up to four PL excitation wavelengths can be combined with an optional eye-safe plug-in interface for a user's additional external excitation lasers. Integrated software provides full data analysis, including automated detection of vertical-cavity surface-emitting laser (VCSEL) optical parameters (cavity-dip, stop-band position), single-layer and multiple-layer thickness fits, film composition and multiple-peak analysis. Moreover,

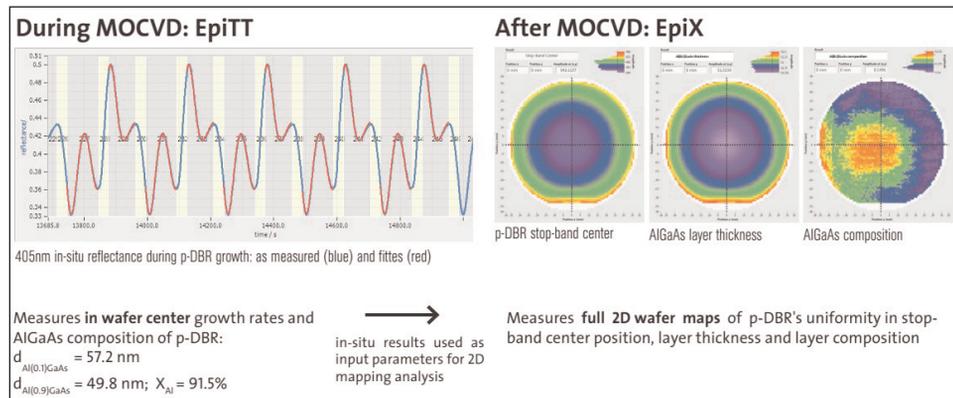


EpiX mapping station (left) with plug-in optical heads (top) for white-light reflectance and PL

users can benefit from a sample's statistics and pass/fail classification at both the wafer level and die level.

The basic design feature of EpiX mapping stations is modularity and customizability in hardware and software. This is key for users that regularly adjust their research projects to new materials and the latest nano-science concepts, says LayTec. EpiX is hence designed as a long-lasting workhorse with multiple upgrade options: more optical heads (wafer bow, reflectance-anisotropy, sheet resistance, wafer thickness, optical transmission), extended wavelength range, software interfaces (e.g. for user-owned spectral analysis libraries) and for using in-situ data measured during epitaxy at the center of the wafer as a starting point for post-epi 2D mapping analysis.

[www.laytec.de](http://www.laytec.de)



Web: [laytec.de](http://laytec.de)

LayTec has launched its new in-situ metrology suite for the monitoring of thin film deposition during the epitaxy of GaAs-based VCSELs:

## EpiTT VCSEL and EpiCurve® TT VCSEL



### Features & Benefits

- Seamless addition of spectral measurement and analysis to the established EpiTT and EpiCurve® TT features of temperature, growth rate and deformation monitoring
- VCSEL epi control by real-time sensing the spectral position of the DBR stop bands and cavity dip and by in-situ measuring the absolute reflectance of the DBRs
- SPC of the growth rates of layers in DBRs and in the cavity
- Wafer temperature sensing at alternative pyro wavelength for specific stop band positions

CS ManTech | Minneapolis, USA

29 April - 7 May

LayTec AG | Web: [laytec.de](http://laytec.de) | [sales@laytec.de](mailto:sales@laytec.de)



## k-Space's annual sales of kSA 400 analytical RHEED systems up 27%

k-Space Associates Inc of Dexter, MI, USA - which supplies in-situ, ex-situ and in-line metrology tools for the thin-film, semiconductor, photovoltaic (PV), solar, automotive, glass and building materials industries - has announced increased annual sales for its kSA 400 product line, with installations of its kSA 400 analytical reflection high-energy electron diffraction (RHEED) system in 2018 up 27% on 2017.

"Our continued increase in system sales is supported by the continued increase in installations for higher-pressure deposition technologies, an increase in sales to OEM partners for new deposition chambers, and customer upgrades motivated by our improved product offering and Windows 10 compatibility," says kSA technical sales manager Dr Carrie Andre. "Features such as triggering with substrate rotation are now more accessible to customers and offer

the customer greater insight into the evolution of their RHEED pattern."

The kSA 400 combines a high-resolution, high-speed and high-sensitivity camera with RHEED-specific acquisition and analysis software. Because of its capabilities, continued new feature enhancements and proven history of over 25 years, the kSA 400 is the preferred analytical RHEED system worldwide for research and manufacturing, claims the firm.

[www.k-space.com](http://www.k-space.com)

## KLA completes acquisition of SPTS' parent Orbotech

Process control and yield management solutions provider KLA-Tencor Corp of Milpitas, CA, USA has completed the acquisition of Orbotech Ltd of Yavne, Israel.

"This new combination extends KLA's market reach within the electronics value chain, opens new high-growth markets for the company, and brings complementary technologies, products and services to our portfolio," says KLA's president & CEO Rick Wallace. "We welcome the talent and experience that Orbotech employees bring to the KLA team. Working together, we will continue to grow and invest in our future as we drive innovation and results."

With the acquisition, KLA diversifies its revenue base and add \$2.5bn of addressable market opportunity in the printed-circuit board (PCB), flat-panel display (FPD), packaging and semiconduc-

tor manufacturing areas. Its defect inspection and metrology products include systems for LED manufacturing. However, as well as providing yield-enhancing and process-enabling solutions for electronics production, Orbotech owns SPTS Technologies Ltd of Newport, Wales, UK (which manufactures etch, PVD and CVD wafer processing solutions for the MEMS, advanced packaging, LED, high-speed RF, and power management device markets). The broader portfolio of products, services and solutions, as well as increased exposure to technology megatrends, should support KLA's long-term revenue and earnings growth targets, it is reckoned.

Orbotech shareholders received \$38.86 per share in cash, and 0.25 of a share of KLA common stock in exchange for each ordinary share

of Orbotech — a total of \$65.93 per share, based on the \$108.26 closing sale price of KLA common stock on the Nasdaq Global Select Market on 19 February.

The transaction should be immediately accretive to KLA's revenue growth model, non-GAAP earnings and free cash flow per share.

KLA will fund the cash portion of the purchase price with cash from the combined company's balance sheet, and from borrowings from KLA's existing revolving credit facility. As previously announced, in conjunction with this acquisition, the board of directors has authorized an additional \$1bn share repurchase program. KLA intends to raise about \$1bn in new long-term public debt to reduce other debt, to repurchase shares, and for general corporate purposes.

[www.kla.com](http://www.kla.com)

## CVD appoints new chief financial officer

CVD Equipment Corp of Central Islip, NY, USA (a designer and maker of chemical vapor deposition, gas control, and other equipment for developing and manufacturing materials and coatings) says that Thomas McNeill has been appointed as chief financial officer & secretary (effective 4 March).

McNeill has been a CFO since 1996 and has 17 years' of SEC reporting experience with two public companies, as well as a range of financial and operational experience.

"McNeill, through his experience in public, manufacturing and engineering companies will bring a

unique insight and perspective to lead the finance team," comments president & board chairman Leonard A. Rosenbaum. "He will be a valuable asset to CVD as our company continues to expand and commercialize exciting new technologies."

[www.cvdequipment.com](http://www.cvdequipment.com)

# Lake Shore demonstrating M91 FastHall measurement instrument at APS March Meeting

In booth 400 at the APS March Meeting in Boston (4–8 March), Lake Shore Cryotronics Inc of Westerville, near Columbus, OH, USA (which makes scientific sensors, instruments and systems for measurement and control under low-temperature and magnetic field conditions) is demonstrating a unique all-in-one instrument for complete Hall analysis.

Suitable for semiconductor material research, the MeasureReady M91 FastHall measurement controller is said to deliver significantly higher levels of accuracy, speed and convenience compared with traditional Hall solutions. Combining all the necessary Hall measurement system functions into a single instrument, the M91 automatically executes measurement steps and provides better measurements faster, especially when working with low-mobility materials, it is



**LakeShore's new M91 FastHall Controller.**

integrated easily with existing laboratory systems, it is claimed, and provides a cost-effective way for researchers to build a new Hall measurement system or upgrade an existing one.

claimed. Most commonly measured materials can be analyzed in a few seconds.

Its speed is mainly due to patented FastHall technology, which eliminates the need to reverse the magnetic field during measurement. This is particularly beneficial when using superconducting magnets, which are relatively slow at completing field reversals. Also, the M91 can be

During the APS meeting's technical sessions, M91 measurement data is being presented by Lake Shore application scientists Dr David Daughton (6 March 9:48am, BCEC Room 152) and Dr Jeffrey Lindemuth (8 March 12:15pm, BCEC Room 108).

[www.aps.org/meetings/march](http://www.aps.org/meetings/march)  
[www.lakeshore.com/products/MeasureReady/M91-FastHall-controller](http://www.lakeshore.com/products/MeasureReady/M91-FastHall-controller)

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# StratEdge opens new global headquarters

## New facility houses high-performance package manufacturing and Assembly Services Division

StratEdge of San Diego, CA, USA (which designs and manufactures packages and provides chip assembly & test services for microwave, millimeter-wave and high-speed digital devices) has moved its global headquarters into new facilities near San Diego (at 9424 Abraham Way, Santee, CA 92071 USA) that incorporate corporate offices, the design and manufacturing operation for StratEdge's high-frequency DC to 63+GHz packages, and its Assembly Services Division.

The new ISO 9001:2015 facility has a Class 1000 cleanroom and Class 100 work area with workstations for performing sensitive operations. It is fully equipped with modern assembly equipment, enabling StratEdge services to include high-speed fine wire wedge and ribbon bonding. The new component placement die attach system is said to be the fastest and most reliable multiple die-type bonder on the market, enabling the



**StratEdge's new global headquarters.**

firm to offer high-accuracy and peak repeatability and performance. StratEdge says that it has a variety of lids and options for their attachment and offers post-assembly services.

"StratEdge has been designing and manufacturing RF and microwave packages since 1992,"

says president & CEO Tim Going. "We have provided post-fired ceramic, low-cost molded ceramic, and ceramic QFN packages for the high-speed digital, mixed signal, broadband wireless, satellite, point-to-point/multipoint, VSAT and test & measurement industries, and specialize in packages for extremely demanding gallium

arsenide (GaAs) and gallium nitride (GaN) devices," he adds. "Our new facility was designed specifically for our manufacturing requirements and to expand our Assembly Services Division so we can offer our customers customized packages and assembly services."

[www.stratedge.com](http://www.stratedge.com)

# MRSI Systems appoints senior director of strategic marketing, targeting China region

Mycronic Group's MRSI Systems of North Billerica, MA, USA (which makes fully automated, high-precision eutectic and epoxy die bonding systems) has appointed Dr Limin Zhou as senior director of strategic marketing to expand its market presence in China. Based in Shenzhen, he will work alongside the firm's existing sales team and representatives in the region.

MRSI says that Zhou's deep knowledge of the photonics market and his extensive network in the Chinese market will help to drive market strategy, product roadmaps and engagement strategies for its key customers in the region.

Zhou joins MRSI as it expands globally in the die bonding market

with the support of its new parent company Mycronic of Täby, north of Stockholm, Sweden. "I see this as an attractive opportunity to join a market leader that continues to adapt to the changing needs of its customers through significant R&D investments and new product launches," comments Zhou.

"Dr Zhou will be an asset to the MRSI team because of his experience in advanced photonics areas such as medical devices, 3D printing and LiDAR and his connections in fiber-optics/photonics industry, deep understanding in automation, and broad exposure to multiple market applications," says Dr Yi Qian, VP of marketing.

Zhou's previous experience cover-

ing the last 20 years includes senior appointments at Neophotonics China, Oclaro China, Sanmina-SCI and JDSU Shenzhen. MRSI says that this has allowed him to develop his leadership skills as an R&D and NPI operational leader with cross-functional responsibility across the whole product life cycle. Market expertise includes the semiconductor, industrial laser and optical and communication industries.

"We are excited for Dr Zhou to join MRSI to develop and execute our China strategy and to bring our powerful value proposition to this high-growth market," says president Michael Chalsen.

[www.mrsisystems.com](http://www.mrsisystems.com)

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# Aehr launches FOX-CP wafer-level test & reliability screening system

At SPIE Photonics West 2019 in San Francisco (5–7 February), Aehr Test Systems of Fremont, CA, USA launched the FOX-CP low-cost single-wafer compact test and reliability verification system for logic, memory and photonic devices as the newest addition to its FOX-P product family.

“The new single-wafer FOX-CP system is integrated with a wafer prober and performs wafer-level testing and reliability cycling for logic, memory and photonic devices,” says president & CEO Gayn Erickson. “This newest addition to our FOX-P product family is optimal for test times ranging from minutes to a few hours or where multiple touchdowns are required to test the entire wafer. It complements the capabilities of the FOX-XP and FOX-NP systems, which are optimal when the test time is measured in hours or days and the full wafer can be tested in a single touchdown. The FOX-CP system offers a low-cost integrated package for both initial evaluations and production applications,” he adds.

“We are very optimistic about the silicon photonics and photonics sensors markets and believe they will be significant growth drivers for Aehr,” Erickson continues. “The rapid growth of integrated optical devices in high-performance servers and data centers, mobile devices, automotive applications and now wearable biosensors is driving substantially higher requirements for initial quality and long-term reliability, and the requirements are increasing with every new product generation,” he adds. “These new applications are driving an entirely new level of quality and reliability expectation for these systems and pose a significant long-term growth opportunity for Aehr.”

The FOX-CP single-wafer test system reduces test cost by functionally testing wafers during reliability screening to identify failing



logic/memory/photonic die before the die are integrated into their final package. This integrated test system with wafer handling and stepping capabilities utilizes Aehr’s custom FOX WaferPak contactor and wafer prober available with thermal chucks to support a wide range of wafer power requirements. Key features of the FOX-CP include:

- 2048 ‘Universal Channels’ per wafer, enabling massively parallel test;
- an innovative Universal Channel architecture, where any channel can be any function — I/O, Device Power Supply (DPS) or Per-pin Precision Measurement Unit (PPMU);
- configurable with Universal Channel Modules, High Voltage Channel Modules or High Current Channel Modules;
- the ability to perform single-touchdown or multiple-touchdown wafer probing;
- available as an integrated solution with prober and custom-designed WaferPak Contactor; and
- compatible with industry-standard wafer probers and probe cards.

## Photonics applications

The FOX-CP system features unique capabilities for testing and reliability screening of vertical-cavity surface-emitting laser (VCSEL) arrays for 3D sensing applications and silicon photonics for 5G communications applications, including:

- testing tens of thousands of arrays per wafer with amps of current per array;
- stabilizing lase and identifying

infant mortalities through extended stress/test programs; and

- electrical and go/no-go optical detection.

One application is to conduct single-touchdown sampling test to confirm that the processing of the wafer is within specified limits and the yield exceeds minimum requirements. The large number of 2A channels (4A with pulsing) available enables a large sample size (as many as 1024 die) with a single touchdown, while providing an individual power supply per die. Individual power supplies per die enable maximum monitoring for device reliability characterization.

Another application is to perform multiple-touchdown (stepping) aging of the full wafer to stabilize the lasing parameters of the die. The large number of high-current power channels can reduce the number of steps by an order of magnitude and increases production throughput. Stabilizing/aging the lasers allows higher-bandwidth performance of the end product, since the laser parameters can be matched and don’t change over time and bring the laser parameters into the narrow range required for effective control of the devices.

## FOX-P platform

The FOX-P Platform is Aehr’s next-generation multi-wafer and singulated die/module test solution that is capable of functional test and burn-in/cycling of photonics devices, flash memories, microcontrollers, sensors and other leading-edge ICs before they are assembled into single- or multi-die stacked packages. The FOX wafer-level systems utilize Aehr’s FOX WaferPak contactors, which provide cost-effective solutions for making electrical contact with a full wafer or substrate in a multi-wafer environment. The configuration with the DiePak Carriers enables burn-in of singulated die and multi-die modules to screen for defects in both the die

and the module assembly process. The resulting known-good die, single-die or stacked-die packaged parts can then be used for high-reliability and quality applications such as enterprise solid-state drives, automotive devices, highly valuable mobile applications, and mission-critical integrated circuits and sensors.

Key features of the FOX-P Platform that contribute to cost-effectiveness include the ability to provide up to 2048 'Universal Channels' per wafer or DiePak carrier, which allows the system to test all the devices on the wafer or DiePak carrier in parallel.

The innovative Universal Channel architecture allows any channel to be any function: I/O, Device Power Supply (DPS) or Per-pin Precision Measurement Unit (PPMU). This enhanced architecture now allows customers to perform per-pin parametric testing, more extensive digital pattern test with deeper data stimulus/capture memory (32M per pin), and deeper scan (768M) optimized for BIST/DFT testing. A single FOX-XP test system may be configured with up to 18 blades of wafer test resources, enabling up to 18 wafers to be tested simultaneously. The foot-

print of the 18-wafer test system is similar to the footprint of typical automatic test equipment (ATE) that can only test one wafer at a time. The highly integrated 2-blade FOX-NP system has a very small footprint and is designed to be easily integrated into product design, reliability and test lab applications. The new FOX-CP single-wafer system is integrated with a wafer prober and performs wafer-level testing and reliability screening.

The FOX-CP system is available now for order and for shipment with standard lead times.

[www.aehr.com](http://www.aehr.com)

## Test & reliability qualification equipment showcased at Photonics West

At the SPIE Photonics West 2019 event in San Francisco (5-7 February), Aehr Test Systems showcased its next-generation solutions for functional test and early failure rate (EFR) test of optical devices in wafer, panel, singulated die or module form, including its FOX-XP system for high-volume production and its new FOX-NP low-cost, small-footprint entry-level system. In addition to functional test and reliability screening, the FOX systems provide the ability to stabilize laser optical performance (critical for the photonics market).

"We are very optimistic about the silicon photonics and photonics sensors markets and believe they will be significant growth drivers for Aehr," says president & CEO Gayn Erickson. Market research firm Yole Développement predicts that silicon photonics technology will grow from being used in a few percent of the total optical transceiver market in 2016 to 35% of the market in 2025, with a market value for transceivers of almost \$4bn in 2025.

"The rapid growth of integrated optical devices in high-performance servers and data centers, mobile devices, automotive applications and now wearable biosensors is driving substantially higher requirements for initial quality and

long-term reliability, and the requirements are increasing with every new product generation," Erickson adds. "These new applications are driving an entirely new level of quality and reliability expectation for these systems and pose a significant long-term growth opportunity for Aehr."

The FOX-P Platform is Aehr's next-generation multi-wafer and singulated die/module test solution that is capable of functional test and burn-in/cycling of photonics devices, flash memories, micro-controllers, sensors and other leading-edge ICs before they are assembled into single- or multi-die stacked packages. The FOX wafer-level systems utilize Aehr's FOX WaferPak contactors, which provide cost-effective solutions for making electrical contact with a full wafer or substrate in a multi-wafer environment. The configuration with the DiePak Carriers enables burn-in of singulated die and multi-die modules to screen for defects in both the die and the module assembly process. The resulting known-good die, single-die or stacked-die packaged parts can then be used for high-reliability and quality applications such as enterprise solid-state drives, automotive devices, highly valuable mobile applications, and mission-critical integrated cir-

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[www.spie.org/conferences-and-exhibitions/photonics-west](http://www.spie.org/conferences-and-exhibitions/photonics-west)

# BluGlass presents latest data on development of RPCVD-grown tunnel junctions for LEDs

At the SPIE Photonics West 2019 conference in San Francisco (5–7 February), BluGlass Ltd of Silverwater, Australia — which was spun off from the III-nitride department of Macquarie University in 2005 — presented its latest remote-plasma chemical vapor deposition (RPCVD) technical data on its recent development of RPCVD-grown tunnel junctions for LED applications.

As an invited speaker, chief technology officer Dr Ian Mann presented the paper 'RPCVD of Group III Nitride Tunnel Junctions for LED Applications' outlining the technical detail and competitive advantages of the firm's patented RPCVD technology for manufacturing GaN-based tunnel junctions (which are a key building block for cascade LEDs). RPCVD-enabled cascade LEDs could address the industry challenge of efficiency droop in LEDs, it is claimed.

A cascade LED is where two or more LEDs are grown in a continuous vertical stack using a tunnel junction to interconnect multiple LEDs in a single chip. This is highly desirable as it could prevent the fundamental challenge of efficiency droop in high-performance LEDs, by decreasing the required current while increasing the light output. Cascade LEDs are expected to enable smaller, cheaper and higher-performing LEDs — the three key areas of interest of the LED industry. To date, functioning tunnel junctions, and hence cascade LEDs,

have been prohibitively difficult to produce.

In December, BluGlass announced that it had capitalized on the unique low-temperature advantages of RPCVD to demonstrate functioning tunnel junctions.

"These exciting results help validate the strong commercial potential of our RPCVD technology to solve a number of the manufacturing challenges associated with the industry's incumbent processes," says managing director Giles Bourne. "Importantly this allows us to further discussions with a range of potential high-value partners in the LED and other semiconductor market segments, as we seek to capitalise on the broader commercial applications for our technology."

There is significant interest in the potential of cascade LEDs and tunnel junctions, as efficiency droop is a well-known problem associated with high-performance GaN-based LEDs. It is a fundamental property of LEDs where the efficiency of the light-output drops as the driving current increases, which means that the majority of today's high-powered LEDs are being operated outside of their peak efficiency.

BluGlass reckons that RPCVD-grown tunnel junctions could be commercially compelling for high-performance nitride devices, including for high-value applications such as LEDs for automotive lighting, UV LEDs for water purification,

high-power laser diodes for industrial machining applications and high-efficiency multi-junction concentrated solar cells.

The LED market is predicted to reach US\$96bn by 2024, with the high-brightness automotive segment (a potential first adopter of cascade LEDs due to strict performance and size requirements) expected to comprise \$22bn by 2024 (23% of the total market).

BluGlass says that the RPCVD process can produce these critical enabling tunnel junctions in the LED device by capitalizing on its inherent competitive advantages. RPCVD operates at hundreds of degrees cooler than incumbent metal-organic chemical vapor deposition (MOCVD) technology and replaces expensive and toxic ammonia with an inert nitrogen plasma. It is also able to achieve the required activation needed for a working tunnel junction during growth. MOCVD relies on complicated and time-consuming ex-situ processing to achieve the required activation. This unique 'as-grown and activated p-GaN' (or AAG) technology is a fundamental advantage of RPCVD, says BluGlass.

The firm says that, since December's announcement of its tunnel-junction capabilities, it has received strong industry interest and looks forward to progressing those discussions with these latest technical details.

[www.bluglass.com.au](http://www.bluglass.com.au)

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# Seoul Semiconductor withdraws lawsuit after Mouser stops selling Everlight LED product in Japan

South Korean LED manufacturer Seoul Semiconductor Co Ltd has concluded a patent infringement lawsuit seeking an injunction on the sale by global electronics components distributor Mouser Electronics Inc of an LED product manufactured by Taiwan-based Everlight Electronics Co Ltd.

In February 2018, Seoul Semiconductor filed a patent infringement lawsuit with the Tokyo District Court, accusing the LED product made by Everlight and sold by Mouser of infringing an LED patent of Seoul's affiliate. Mouser has agreed not to export the accused Everlight LED product in Japan, and Seoul has therefore agreed to withdraw the lawsuit.

The patented technology involved serves to efficiently extract light emitted from the internal LED structure by attaching a light-reflection structure to the LED chip, increasing light extraction efficiency significantly.

Seoul says it has established hundreds of patents arising from this patented technology, which covers an LED module, package, chip and epitaxial structure. The patented technology has been widely applied to mid-power LED products, such as lighting, automobiles and mobile phones, with power consumption of less than 1W.

Seoul has already obtained an injunction against certain Everlight LED products in Germany. In

December, the District Court of Düsseldorf rendered judgments in favor of Seoul Semiconductor's infringement claims, including ordering an injunction against sales of the accused Everlight products. The court also ordered the recall of the accused Everlight products sold after 13 July 2012 from the distributor's commercial customers.

"To create a fair competition market, we will continue enforcement efforts to prevent manufacturers and distributors from selling suspected infringing products," says Nam Ki-bum, sales & marketing executive VP at Seoul.

[www.SeoulSemicon.com](http://www.SeoulSemicon.com)

[www.mouser.com](http://www.mouser.com)

[www.everlight.com](http://www.everlight.com)

## Seoul Semiconductor and Sensor Electronics Technology present 'UV LEDs: From Niche to Mainstream' at Strategies In Light

At the annual Strategies in Light 2019 conference & exhibition at the Mandalay Bay Convention Center in Las Vegas (27 February – 1 March), in addition to showcasing its latest LED innovations, on 1 March Dr Peter Barber, director of business development for South Korean LED maker Seoul Semiconductor and Sensor Electronics Technology Inc (SETi) in the Americas, is giving a technical presentation 'UV LEDs: From Niche to Mainstream'.

"With the dynamic evolution of UV technology from the earliest mercury vapor (Hg) lamps to today's UV LEDs, we've seen significant increases in efficiency, power output and reliability," says Barber. "These improvements have led to an expansion of the applications where UV LEDs can be employed, including disinfection systems, as well as horticultural lighting applications."

Two of Seoul Semiconductor's leading products – SunLike Series natural-spectrum LEDs and the



**Dr Peter Barber.**

24W NanoDriver Series ultra-miniature LED drivers — have been named as finalists in the LEDs Magazine's 2019

Sapphire Awards, presented annually at Strategies in Light. Based on a new technology, SunLike Series natural-spectrum LEDs

**We've seen significant increases in efficiency, power output and reliability. These have led to an expansion of the applications where UV LEDs can be employed, including disinfection systems, as well as horticultural lighting**

implement a spectrum close to natural sunlight.

Introduced in June 2017, SunLike Series natural-spectrum LEDs were co-developed through the combination of Seoul Semiconductor's optical semiconductor technology and Toshiba Materials' TRI-R technology, which defines its original concept as "the light closest to the sun for human well-being". TRI-R technology enables the spectrum of natural sunlight to be reproduced by a white LED light source.

Another Seoul Semiconductor technology advance nominated as a Sapphire Award finalist is the NanoDriver Series LED drivers — which feature a unique power topology that results in smaller size, increased efficiency and lower costs — with power densities up to 10X higher than conventional LED drivers. The NanoDriver Series devices, rated for 16W and 24W, are the industry's smallest LED drivers at just 13.5mm<sup>2</sup>.

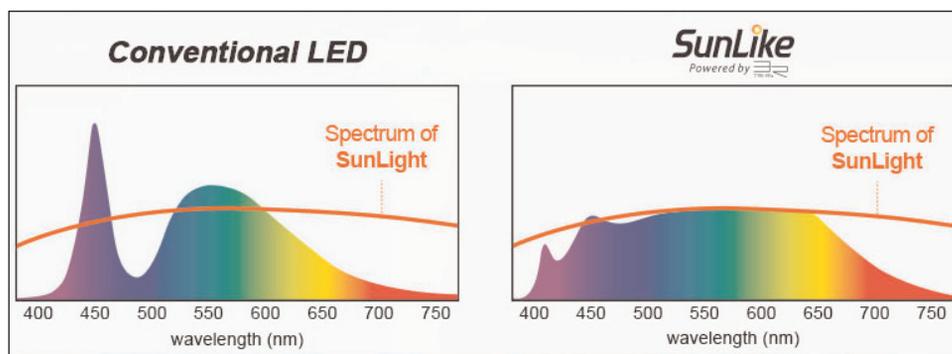
[www.strategiesinlight.com](http://www.strategiesinlight.com)

# Seoul Semiconductor's SunLike Series natural-spectrum LEDs adopted by Rofianda for horticulture LED lighting

South Korean LED maker Seoul Semiconductor Co Ltd says that its SunLike Series natural-spectrum LEDs have been adopted for horticulture LED lighting by Tilburg-based lighting firm Rofianda B.V. of The Netherlands (the world's second largest agricultural exporter).

Natural sunlight is a key factor in a plant's growth cycle, but most growers cultivating a variety of crops under sunlight have experienced difficulties in regulating their growth cycles due to adverse seasonal conditions. Replacing sunlight with LED lighting that closely matches natural sunlight enables growers to control the growth cycles and development of crops year-round in greenhouses and indoor farms.

SunLike Series natural-spectrum LEDs are claimed to be the first LEDs to produce light that closely matches the spectrum of natural sunlight. The LEDs adopted by Rofianda achieve a full spectrum of light wavelengths from 380nm to 740nm, similar to the spectral curve of natural sunlight, with a color temperature of 5600K optimized to daylight spectra and color properties of CRI97 and CQS97.



Seoul Semiconductor says that, in co-operation with Rofianda, it has delivered an optimal horticulture lighting solution that fulfills the requirements of the light source for effective cultivation of all varieties of crops, flowers and cannabis.

Rofianda is introducing its horticulture lighting with SunLike at the annual HortiContact Fair in Gorinchem, The Netherlands (19–21 February).

"SunLike Series natural spectrum LEDs are the first and only true sunlight LEDs that enable growers to ensure better yields and a consistently high quality of crops," comments Rofianda director Ronald Gronsveld. "Market demand for horticultural LED lighting with SunLike LEDs will expand," he believes.

"The horticulture lighting market is growing fast, and our SunLike Series natural-spectrum LEDs will offer the considerable benefits for customers to achieve optimal horticulture lighting solutions," reckons Ki Bum Nam, sales & marketing vice president at Seoul Semiconductor.

SunLike Series natural spectrum LEDs were co-developed through the combination of Seoul Semiconductor's optical semiconductor technology and Toshiba Materials' TRI-R technology, which defines its original concept as "the light closest to the sun for human well-being". TRI-R technology enables the spectrum of natural sunlight to be reproduced by a white LED light source.

[www.rofianda.com](http://www.rofianda.com)

## Seoul Semiconductor joins LightingEurope industry association

South Korean LED maker Seoul Semiconductor Co Ltd has become a member of LightingEurope, the European lighting industry association whose members represent more than 1000 European companies (most of which are small- and medium-sized enterprises), a total workforce of more than 100,000 people in Europe, and an annual turnover estimated to exceed €20bn.

The main mission of the LightingEurope industry association is to promote efficient lighting practices for the benefit of the global environment, human comfort, and the

health and safety of consumers. Seoul Semiconductor says that, as a member, it will be better informed about European Union (EU) lighting policies that impact its corporate strategies for LED technology development and application, and thus be able to respond more quickly to lighting markets in Europe.

LightingEurope membership also provides Seoul Semiconductor with advance notice on upcoming policies and laws impacting its business, access to guidelines for help in interpreting and complying with EU rules, and participation in forums for industry to exchange

views and reach consensus.

"The wide range of applications [in] which Seoul Semiconductor's products are used illustrate how lighting technologies add value to society," comments Ourania Georgoutsakou, the secretary general of LightingEurope. "With their strong technical expertise and their presence in Europe, Seoul Semiconductor will make a valuable contribution to LightingEurope's work to shape a positive EU policy framework for the lighting industry in Europe," he adds.

[www.lightingeurope.org](http://www.lightingeurope.org)  
[www.SeoulSemicon.com](http://www.SeoulSemicon.com)

## SemiLEDs' quarterly revenue falls by half

For its fiscal first-quarter 2019 (to end-November 2018), LED chip and component maker SemiLEDs Corp of Hsinchu, Taiwan has reported revenue of \$972,000, roughly halving from \$1.95m last quarter and \$2m a year ago.

Gross margin has worsened further, from +3% a year ago and -11% last quarter to -23%. Likewise, operating margin has worsened from -43% a year ago

and -62% last quarter to -105%, despite operating expenses being cut from \$1m last quarter to \$0.8m.

However, although up on \$0.4m a year ago, GAAP net loss has been cut from \$1.13m (\$0.32 per diluted share) last quarter to \$983,000 (\$0.27 per diluted share). Due to the excess capacity charges experienced for the last few years, considering the risk of technological

obsolescence and based on the sales forecast, the firm disposed of certain idle equipment, reducing the net loss.

Cash and cash equivalents hence fell during fiscal 2018 from \$3.4m to \$2.6m.

For fiscal second-quarter 2019 (to end-February), SemiLEDs expects revenue to rebound to \$1.5m.

[www.semileds.com](http://www.semileds.com)

## Vishay launches long-life 18mW mid-power UVC LED in 3.5mm x 3.5mm x 1.2mm ceramic quartz SMD package

Vishay Intertechnology Inc of Malvern, PA, USA has launched a ceramic mid power ultraviolet (UVC) light-emitting diode for sterilization, sanitation and purification applications.

Designed to replace mercury UVC lamps, the Vishay Semiconductors VLMU35CM..-280-120 delivers what is claimed to be an extremely long lifetime in a compact 3.5mm x 3.5mm x 1.2mm surface-mount package.

Featuring a quartz window, the device has an emission angle of  $\pm 60^\circ$  and radiant power to 18mW



at a current of 100mA without the need for an external lens. Fabricated using aluminium gallium nitride (AlGaN) technology, the VLMU35CM..-280-120 features forward current up to 150mA, forward voltage down to 4V, and a

wavelength range of 270–290nm.

The LED's specifications make it suitable for water and air purification, physical surface sterilization, medical disinfection and portable sanitizers. RoHS-compliant, halogen-free and Vishay Green, the VLMU35CM..-280-120 is compatible with reflow soldering processes and features a Moisture Sensitivity Level of 3 in accordance with J-STD-020.

Samples of are available now. Production quantities are available with lead times of four weeks.

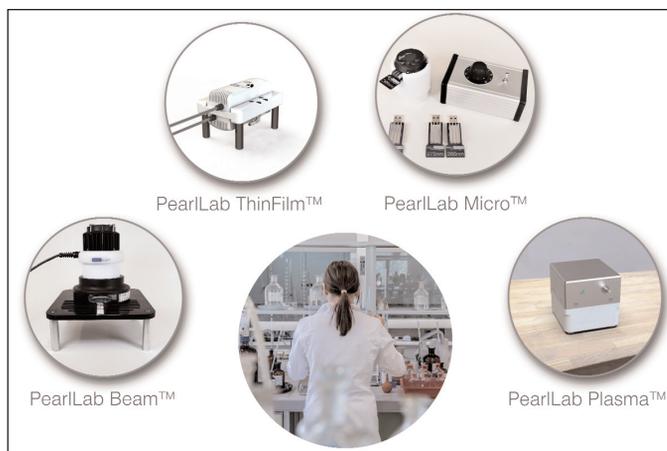
[www.vishay.com/ppg?84938](http://www.vishay.com/ppg?84938)

## AquiSense announces new UV research tools

Nikkiso Group company AquiSense Technologies LLC of Erlanger, KY, USA (which designs and manufactures water, air and surface disinfection systems based on UV-C LEDs) has launched the PearlLab product line of ultraviolet (UV) research tools for scientific studies, offering access to the latest in UV-C LED and plasma lamp technology.

Adding to the existing PearlLab Beam product (used to determine UV dose response data), AquiSense has launched three new products to assist researchers.

The PearlLab Micro is a flow-through or batch operation tool with interchangeable UV wave-



lengths on a convenient USB plug-gable format. The PearlLab Thin-Film is designed for disinfection for low UV transmittance (UVT) or high

UV dose applications. The PearlLab Plasma enables research below 230nm without the use of a mercury vapor lamp.

"UV LED technology continues to develop at a rapid pace and these tools allow researchers to develop applications in fields previously

thought impenetrable for UV technology," says chief technology officer Jennifer Pagan.

[www.aquisense.com/research](http://www.aquisense.com/research)



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# Cree's quarterly revenue grows 12% year-on-year, driven by Wolfspeed's organic growth of over 50% SiC adoption driving acceleration in Wolfspeed capacity expansion

For its fiscal second-quarter 2019 (ended 30 December 2018), Cree Inc of Durham, NC, USA has reported revenue of \$413m, up 1% on \$408.3m last quarter and 12% on \$367.9m a year ago.

Revenue for the Wolfspeed business (Power & RF devices and silicon carbide materials) was a record \$135.3m (32.8% of total revenue), up 6% on \$127.4m (31.2% of total revenue) last quarter and up 92% on \$70.6m (19.2% of total revenue) a year ago (or more than 50% growth on an organic basis, excluding the Infineon's RF Power business, acquired on 6 March 2018).

LED Products sales were \$145.2m (35.1% of total revenue), down 1% on \$146.8m (36% of revenue) last quarter and 5% on \$152.7m (41.5% of revenue) a year ago, but slightly ahead of target.

Lighting Products sales were \$132.5m (32.1% of total revenue), down 1% on \$134.1m (32.8% of total revenue) last quarter and 8% on \$144.6m (39.3% of total revenue) a year ago, but slightly ahead of target.

On a non-GAAP basis, gross margin has risen further, from 25.7% a year ago and 32.1% last quarter to 33.3%, and well above the target.

Specifically, Wolfspeed gross margin was 47.8%, down from 48.4% a year ago but up from 47.4% last quarter, "in line with our targets as the team continues to do an excellent job balancing the challenges of rapidly increasing capacity while maintaining yields," says president & CEO Gregg Lowe.

LED Products gross margin has risen further, from 25.3% a year ago and 28.1% last quarter to an above-target 30% despite slightly the lower LED revenue, driven by strong execution and higher licensing revenue.

Lighting Products gross margin has also risen further, from 15.9% a year ago and 23.2% last quarter to an above-target 25.7% (the

fourth consecutive quarter of improvement by more than 100 basis points). This is attributed mainly to product cost reductions, improved operational efficiencies, and being more selective with the business pursued.

"In terms of Lighting, the team delivered another solid result towards the objective of fixing the business as both revenue and gross margin were better than expected," notes Lowe. "The team has done an outstanding job improving quality through improved processes. Over the last four quarters, we've released 30 new products and shipped over 270,000 units of those new products, with excellent performance in the field and high levels of customer satisfaction."

Operating expenditure (OpEx) has risen from \$104m (25.5% of revenue) last quarter to \$111m (26.9% of revenue), due mainly to higher Wolfspeed R&D spending and a greater number of days in the quarter as well as a full-quarter impact of the annual merit increases that went into effect in September.

Compared with a net loss of \$0.66m (\$0.01 per diluted share) a year ago, net income was \$23.2m (\$0.23 per diluted share), up from \$22m (\$0.22 per diluted share) last quarter and well exceeding the targeted \$15–19m (\$0.15–0.19 per diluted share). This was driven by another

record quarter for Wolfspeed combined with gross margin improvement in all three businesses.

Cash flow from operations was \$92.3m (rebounding from \$34m last quarter, and up on \$51.7m a year ago). Capital expenditure (CapEx) was \$39m. Free cash flow was hence \$53.3m (compared with just \$0.5m a year ago and –\$5.8m last quarter), driven by strong working capital management as well as an upfront payment related to wafer supply agreements.

With zero borrowed on the firm's line of credit and a convertible debt with a face value \$575m, cash and investments rose during the quarter from \$665.5m to \$723.7m. Capital allocation priorities remain focused on expanding capacity in the Wolfspeed business.

"This performance is particularly gratifying when considering the current challenges associated with tariffs and global trade tensions," says CEO Gregg Lowe. "While we're certainly not immune to the turmoil in our served markets, our business is demonstrating a resiliency that we believe shows we are on the right track with our strategy."

For fiscal third-quarter 2019 (ending 31 March), Cree targets revenue of \$385–405m, with Wolfspeed up a few percent sequentially as the adoption of silicon carbide (SiC) and gallium nitride (GaN) continues, but LED Products down 5% and Lighting Products down 10% (both due to normal seasonality).

Gross margin is expected to drop slightly to 32%, with Wolfspeed at 48% (up both year-on-year and sequentially), LED Products at 27% (up year-on-year, but down sequentially due to seasonally lower volume and lower licensing revenue) and Lighting Products at 24% (up about 500 basis points year-on-year, but down sequentially due mainly to seasonally lower revenue).

**For fiscal 2019, we still target capital investments of about \$220m [14% of revenue], primarily driven by expanding Wolfspeed's production capacity to support forecasted long-term customer demand.**

► Operating expenses should be cut sequentially to \$109m, even as growth investment increases in Wolfspeed. "While changes in OpEx can vary from quarter-to-quarter for a variety of reasons, including the timing of R&D projects, marketing spend around trade shows and when IP cases go to trial, our long-term objective remains to drive OpEx lower as a percent of sales even as we increase our investments in growth initiatives," notes chief financial officer Neill Reynolds.

Including a \$0.03–0.04 decrease from the impact of the tariffs, net income should fall to \$13–19m (\$0.13–0.19 per diluted share).

"For fiscal 2019, we still target capital investments of about \$220m [14% of revenue], primarily driven by expanding Wolfspeed's production capacity to support forecasted long-term customer demand," says Reynolds. "As we continue to ramp this new capacity, we could have some variability in our initial production yields and factory utilization that may reduce our near-term Wolfspeed gross margin," he cautions.

"We've reached the tipping point in the adoption of electric vehicles and the adoption of silicon carbide. Nowhere was this more evident than at the Electronica and CES trade shows where I met with

numerous automotive OEMs and tier-1 suppliers who are expanding their electric vehicle product lines," says Lowe.

"A recent analysis by Reuters noted that carmakers have announced plans to spend at least \$300bn on electrification projects. Within the EV market, the interest in silicon carbide is extremely high because the value proposition is so strong. Utilizing silicon carbide saves space, reduces cooling requirements, and allows for a smaller, lower-cost battery. These benefits far outweigh the incremental cost," he adds.

"With this becoming better understood, the conversation is shifting from the merits of utilizing silicon carbide to ensuring that an adequate supply will be available as EV production ramps," Lowe continues. "These trends are being validated by our long-term [150mm-diameter silicon carbide] wafer supply agree-

**In RF, the wireless telecom market is moving towards GaN... We are in the process of adding GaN production capacity to meet the increasing demand that we're seeing**

ments, which now total in excess of \$450m. Our most recent announcement with STMicro alone is worth over a \$0.25bn."

"Our Power products business continues to develop with a sales funnel that is building very nicely. In Q2, we saw good growth in the total value of projects in the pipeline compared to Q1," notes Lowe.

"In RF, the wireless telecom market is moving towards GaN, which enables faster 4G and the transition to 5G given the wider bandwidth, higher frequency and higher efficiency... We are in the process of adding GaN production capacity to meet the increasing demand that we're seeing," he adds.

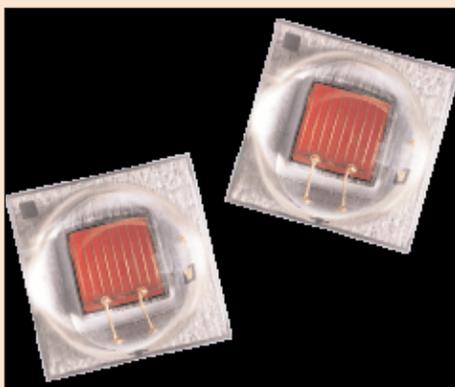
Cree has already doubled capacity for its Power business and its Materials business one quarter ahead of schedule. It is also doubling capacity again, and is working to try to pull that in within the previously stated 24-month timeframe.

"This past quarter, we reached an agreement with Arrow Electronics, positioning Arrow as the largest global distributor of our SiC power and GaN RF product portfolios. Arrow's global salesforce allows us to reach more markets and customers quicker and more efficiently through a proven partner solution," concludes Lowe.

## Cree's new XLamp XP-E2 Photo Red and Far Red LEDs boost performance for horticulture lighting efficiency

Cree has launched the next-generation XLamp XP-E2 Photo Red (660nm) and Far Red (730nm) LEDs for horticulture applications (available now with standard lead times).

Providing a drop-in upgrade for previous-generation XP-based horticulture designs with the same mechanical and optical characteristics, the new-generation XP-E2 LEDs provide performance improvements of up to 57% in Far Red and up to 21% in Photo Red and are said to outperform competing LEDs by up to 68%, it is claimed. The higher-performance horticulture LEDs increase the efficiency of



LED luminaires and shorten their payback periods, making it more affordable to grow food under optimized lighting, the firm adds.

"LEDs for specialty applications,

including architectural lighting and horticulture, are a core part of our product strategy," says Claude Demby, Cree LEDs senior VP & general manager. "Cree is first to enable full-spectrum luminaires that employ Photo Red and Far Red LEDs to deliver 50% energy savings over sodium-based lighting systems," he adds. "This upgrade to our horticulture LEDs demonstrates our commitment to delivering industry-leading high-power LED performance."

[www.cree.com/led-components/products/xlamp-leds-discrete/xlamp-xp-e2](http://www.cree.com/led-components/products/xlamp-leds-discrete/xlamp-xp-e2)

# Osram's quarterly revenue falls 15% year-on-year

## Sales impacted by weak mobile, lighting and auto markets, especially in China, plus political uncertainties

Osram of Munich, Germany says that unfavorable developments in the automotive industry, especially in China as well as within the mobile devices sector, impacted its fiscal first-quarter 2019.

Political adversities such as international trade disputes, weakened demand for general lighting and the after-effects of the emission test procedure WLTP (Worldwide Harmonised Light Vehicle Test Procedure) also drove customer uncertainty. In addition, Osram's customers reduced their inventories towards the end of 2018.

On a comparable basis, quarterly revenue fell by about 15% year-on-year to €828m. Earnings before interest, taxes, depreciation and amortization (EBITDA), before special items, was also down, to €93m. The adjusted EBITDA margin has fallen from 18.5% to 11.3%.

These figures no longer include the business activities of Sylvania Lighting Solutions in North America (for which a sales agreement was signed in January) or the European luminaire business (which is up for sale). Both are accounted for as discontinued operations from fiscal first-quarter 2019 (leading to a value adjustment being made that impacted net income).

"There was an increased headwind from our markets in the past quarter, in particular the automo-

tive cycle has deteriorated significantly," says OSRAM Licht AG CEO Olaf Berlien. "But demand has also declined in the mobile devices and general lighting sectors," he adds.

The market weakness is reflected in all three of Osram's business segments:

- The Opto Semiconductors (OS) division saw a drop in revenue of about 17% year-on-year, reflecting not only the economic effects of customers in the automotive industry and general lighting but also a reduction in customer inventories. Automotive segment revenue was down 11%.

- The automotive (AM) market declined significantly, especially in China where (according to the market researcher IHS Markit) car production fell by more than 15% on a quarterly basis. Numerous Western manufacturers have also lowered their expectations recently.

- In the Digital (DI) segment, revenue fell by about 17%, due mostly to weak market development in the general lighting segment.

Because of the numerous uncertainties, the perspective for the upcoming quarters remains significantly restricted, says the firm. The management board has initiated countermeasures, aiming also to improve revenue and margins. In particular, significant structural measures have been initiated in the

Opto Semiconductors division, intended to secure the forecast for the year. However, achievement of the annual targets is subject to a revival in incoming orders in the upcoming months, cautions the firm.

As announced, Osram will in the future hone its focus on photonics and optical technologies beyond lighting, as reflected by the new organizational structures initiated at the start of the new fiscal year. According to Bayerischer Rundfunk, this involves cutting 300 of the 2800 jobs in Regensburg by the end of September through voluntary redundancy (800 Regensburg staff had already been working 35 rather than 40 hours per week since the beginning of this year). The firm also wants to cut up to 240 temporary workers. Previously, over the past three years, Osram Opto Semiconductors' staffing had been increased from 2000 to 2800, in response to rapid growth rates (of up to 24% annually).

Osram is further sharpening its profile and focusing on high-growth markets, including optical semiconductors, automotive and digital applications. With this, Osram is moving closer to its markets and therefore expects to balance its portfolio more effectively. This long-term growth strategy remains intact, says the firm.

[www.osram.com](http://www.osram.com)

## Osram's OSOLON Square LEDs available via Rutronik

Rutronik Inc (the world's 11th largest electronic components distributor, with annual sales of \$1bn) has announced the availability of Osram's OSOLON Square series LEDs, a family of compact high-power LEDs for a wide range of high-density solid-state lighting arrays.

Designed for both indoor and outdoor general lighting applications,

the OSOLON Square LEDs feature an ultra-compact 3mm x 3mm (3030) package, with a range of correlated color temperatures (CCT) from 2700–6500K and a color rendering index (CRI) of 70, 80 or 90. The LEDs are binned by key parameters at 85°C, which more closely matches real-world application conditions. For horticultural lighting applications, the

OSOLON Square LEDs are available in deep blue (439–461nm) and hyper-red (635–666nm) wavelengths.

"The OSOLON Square LEDs provide superior performance combined with long lifetimes and excellent thermal performance," comments Mary Ellen Bauchman, Rutronik's director of product marketing North America.

[www.rutronik-tec.com](http://www.rutronik-tec.com)

# Osram's 140mW direct green laser enables projection from smartphones

Osram Opto Semiconductors GmbH of Regensburg, Germany says that its new PLT3 520D direct green laser diode achieves an unprecedented high pulse output of 140mW. In addition, its efficiency has been increased to a typical value of 8%. Due to these improvements, it is now possible to turn a smartphone into a small cinema projector, since the small display of the device can be enlarged several times over.

Green lasers for projector applications need to have not only outstanding beam characteristics but also high optical performance in order to deliver sharp and bright images. Although a projector also needs red and blue lasers, green is the crucial color in RGB solutions – and also the color that poses the greatest challenges in production.

Up to now, RGB laser projections for smartphones, based on a red, green and blue laser, often had brightness problems due to the often insufficient brightness of the green laser. Green light has special importance in RGB applications because the human eye is most sensitive in the green spectral range. The brighter the green laser shines on a surface, the brighter and stronger the projected image appears to the viewer.

With its PLT3 520D now offering 140mW at a current of 300mA in pulsed mode (50% duty cycle), Osram has surpassed the prior limit of 80mW for green single-mode lasers.

A further advantage of the diode is its compact and space-saving TO38 metal housing, with a diameter of only 3.8mm. With an emission wavelength of 520nm, the laser diode

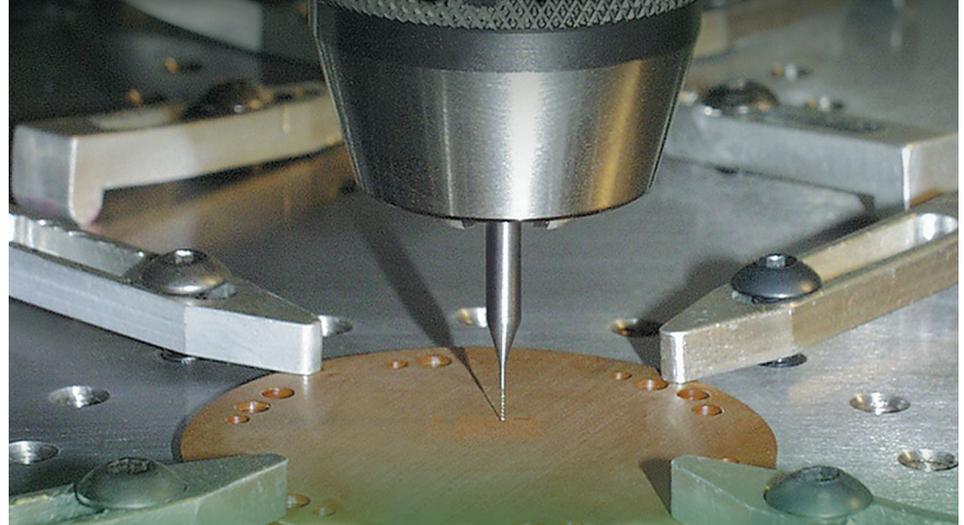
has been specially developed for laser projection applications that use a MEMS scanner as the image encoder.

"Thanks to Osram's long tradition and expertise in the laser sector, we have succeeded in driving for-

ward developments in this key technology," says marketing manager Pedro Muñoz. "Users can be confident that this technology will open up additional functions on smartphones in the medium term."

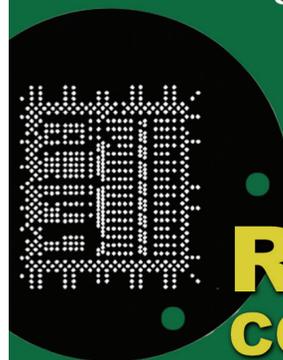
[www.osram-os.com](http://www.osram-os.com)

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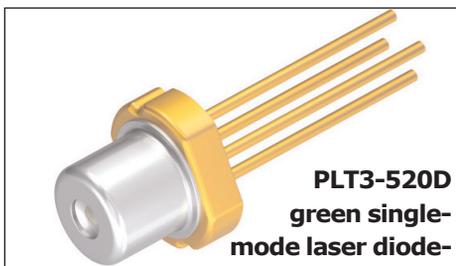


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**PLT3-520D**  
green single-  
mode laser diode-

## Osram launches second-generation blue multi-mode laser for high-beam automotive forward lighting, tripling luminance over LEDs

Osram Opto Semiconductors GmbH of Regensburg, Germany has launched the PLPT9 450D\_E A01, its second-generation blue multi-mode laser which, used as a light source for auxiliary high-beam automotive forward lighting, can illuminate the road further than a conventional high beam, making driving at night safer (since driving at dusk or at night puts great strain on the driver's eyes and reduces their ability to concentrate).

In terms of brightness, laser diodes offer advantages compared with LEDs. At a typical operating current of 2.2A, the PLPT9 450D\_E A01 laser reaches an optical output of 3.5W and emits blue light with a

wavelength of 447nm. With the help of appropriate optics, the light is focused to a point only a few microns in diameter. A special phosphor converter converts the blue light into the white light required for front lighting applications. The luminance achieved is 600cd/mm<sup>2</sup>, three times higher than the 200cd/mm<sup>2</sup> of an LED light source, doubling the range to 600m.

Qualified for use in cars, the PLPT9 450D\_E A01 is approved for an operating temperature range of -40°C to 120°C. Compared with the first generation with three pins, the TO90 package contains only two pins, allowing much easier

connection and heat dissipation. Due to the laser's compact dimensions of only 9mm in diameter and a height of <4.5mm (without contact pins), headlights can be made much smaller in the future, opening up new design possibilities and performance values for applications in car headlights.

"With our newly developed laser diode, car lights can be designed and built even smaller than before — without compromising light output," says Walter Rothmund, marketing manager Automotive for Emitter Laser Sensor at Osram Opto. "It combines powerful light with compact dimensions."

[www.osram.com](http://www.osram.com)

## Ushio America showcases new laser & LED products from Necsel, Pd-Ld, Ushio Inc and Ushio Opto

At SPIE Photonics West 2019 in San Francisco, CA, USA (2-7 February), light source manufacturer Ushio America Inc of Cypress, CA, USA (a subsidiary of Ushio Inc of Tokyo, Japan) exhibited new lighting solutions including products from the Necsel, Pd-Ld, Ushio Inc and Ushio Opto Semiconductors brands.

Established in 1964, Ushio Inc of Tokyo, Japan produces lamps, lasers and LEDs in a range of ultraviolet, visible and infrared wavelengths, as well as optical equipment and cinema-related products incorporating these light sources.

Ushio demonstrated high-power visible lasers, including red, green, blue and multi-wavelength modules that feature Necsel's patented technology. A new addition to its family of laser products, Necsel Yellow, produces 1W of power at 577nm from a package of less than one cubic inch. Ushio says that Necsel's lasers have transformed cinema

projection and specialty lighting markets, as well as developed a broad application base across a variety of industries.

Ushio also showcased Pd-Ld fiber-coupled emitters and detectors, which includes single-mode and multi-mode fiber-coupled diode lasers. This product family is often used in communication and instrumentation applications within the OEM and end-user marketplace.

In addition, Ushio Opto Semiconductors Inc (UOS) exhibited its new high-power red laser diodes, continuous broad band spectrum LEDs, and high-power short-wavelength infrared (SWIR) LEDs. UOS is introducing a new record-power 3.5W (pulsed)/2.4W (cw) multi-mode laser diode emitting at 638nm, as well as a 300mW pulsed single-mode laser diode at 685nm and a 200mW CW single-mode laser diode at 660-690nm.

UOS also debuted its epitax Spectro series, a new category of

continuous broad-band-spectrum LEDs emitting at 400-1000nm. Additionally, its SWIR LED series, which achieves what is claimed to be the highest output power within the 1000-1650nm range, will increase its available power by 100% and include the new wavelength of 1750nm.

Also, Ushio America's president & CEO William F. Mackenzie presented on how advances in Ushio's laser products are enabling more applications. "Over the last 10 years, Ushio has grown its solid-state solutions business through lasers, LEDs, modules and systems," says Mackenzie. "Improvements in epitaxy, laser packages and modules are supporting dramatic reductions in the cost of laser light, thereby creating new applications and markets."

[www.ushio.co.jp/en](http://www.ushio.co.jp/en)

[www.necsel.com](http://www.necsel.com)

[www.ushio.com](http://www.ushio.com)

# MKS launches Ophir integrating spheres for measuring optical power in VCSELs

At the Photonics West 2019 event in San Francisco (5–7 February), MKS Instruments Inc of Andover, MA, USA (which provides instruments, subsystems and process control solutions that measure, monitor, deliver, analyze, power and control critical parameters of manufacturing processes) has launched Ophir IS6D integrating spheres for measuring the optical power of widely divergent laser diode sources, such as vertical-cavity surface-emitting lasers (VCSELs). Part of the Ophir Integrating Spheres series of products, the new spheres can accurately measure light that diverges by up to  $\pm 85^\circ$ . Each sphere is delivered as a calibrated unit with a photodiode detector.

The IS6D-VIS/UV/IR measures powers from 300nW to 30W over wavelengths of 200–1800nm. It has a 1-inch (25mm) input port designed

to collect light at angles up to  $\pm 60^\circ$ .

The IS6D-IR-170 measures powers from 20 $\mu$ W to 30W over wavelengths of 700–1800nm. It features a specially designed gold-coated 8mm input port that collects light at angles up to  $\pm 85^\circ$ .

Both integrating spheres can be fitted with detachable apertures of 5mm, 7mm or 10mm diameter to restrict the entrance of the integrating sphere to a particular light source, reducing unwanted effects from the PCBs or carriers on which the light source is mounted. The apertures are magnetically attached to the port, making them easy to attach and detach. Each aperture is also coated with a special low-reflectivity coating that prevents changes to the calibration of the integrating sphere.

"VCSELs have widely divergent beams that require input ports to

be adapted to wide angles as well as sources to be placed very close to the measurement sphere," says Reuven Silverman, general manager of the Ophir Photonics Group of North Logan, UT, USA (a division of Ophir Optronics Solutions Ltd of Har Hotzvim, Jerusalem, Israel). "This can cause a multitude of reflection problems which can upset the sphere's calibration. The new Ophir IS6D integrating spheres feature detachable apertures that restrict the field of view so that only the VCSEL emitter is 'seen' by the sphere. They also include a special low-reflectivity paint so as not to affect the accuracy of the measurement device."

The Ophir IS6D-VIS/UV/IR and IS6D-IR-170 are available now. OEM prices available on request.

[www.mksinst.com](http://www.mksinst.com)

[www.ophiropt.com/photronics](http://www.ophiropt.com/photronics)

## Instrument Systems showcases fast, high-resolution spectroradiometers for laser & VCSEL characterization

In the German pavilion at Photonics West 2019 in San Francisco (5–7 February), Instrument Systems GmbH of Munich, Germany (a subsidiary of Konica MinoIta Group since 2012) showcased its premium-class high-resolution spectroradiometers for the characterization of laser light sources and displays. The reference device CAS 140D forms the basis of the system and is supplemented by the high-resolution CAS 140CT-HR model. Both devices were shown in simulated applications.

In combination with various accessories, the color coordinates, color temperature or color rendering index of LED modules and displays can be measured with highest precision. As they are said to be particularly stable and reliable in operation, the CAS series of array spectroradiometers is suited to 24/7 use in the production line.

### High-resolution spectroradiometry

Instrument Systems developed the CAS 140CT-HR high-resolution array spectroradiometer specifically for the absolute characterization of narrow-band emission sources. It delivers measurement results with a high spectral resolution of up to 0.2nm half-band width, accompanied by short measurement times as low as 9ms. In particular, the CAS 140CT-HR is said to offer advantages compared with conventional technologies for the fast testing of laser diodes or vertical-cavity surface-emitting lasers (VCSELs). Dispersive, scanning or Fourier-transformed infrared spectrometers (FTIR) have movable parts that react sensitively to production vibrations. The CAS 140CT-HR contains fixed components and is said to be particularly stable and

reliable in operation, making it suitable for exacting tasks in production and the laboratory.

### Display measurements set up individually

Premium spectroradiometers can be set up as a DTS system for individual display measurements. The light radiation is launched with the TOP 200 telescopic optical probe connected to the spectrometer by an optical fiber. Due to the flexible fiber connector, the measurement adapter can easily be changed and the system quickly configured for other applications, e.g. LED measurement. The system measures, among other things, the radiance and luminance and the color of displays and backlit symbol displays. The DTS system can be employed universally for various display technologies (e.g. LCD, LED or OLED).

[www.instrumentsystems.de](http://www.instrumentsystems.de)

## Christine Wang elected to National Academy of Engineering

Massachusetts Institute of Technology (MIT) says that six of its researchers are among the 86 new members and 18 foreign associates elected to the US National Academy of Engineering (NAE).

Academy membership honors those who have made outstanding contributions to "engineering research, practice or education including, where appropriate, significant contributions to the engineering literature," and to "the pioneering of new and developing fields of technology, making major advancements in traditional fields of engineering, or developing/ implementing innovative approaches to engineering education."

The six new NAE members at MIT include Dr Christine Wang, a senior staff scientist in the Laser Technology and Applications Group at MIT's Lincoln Laboratory, for contributions to epitaxial crystal growth of III-V compound semiconductors and the design of organometallic vapor-phase epitaxy (OMVPE) reactors.



Wang (who holds SB, MS and PhD degrees in materials science and engineering from MIT) is pursuing research on the optimization of III-V materials for optoelectronic devices. According to MIT, she pioneered the concepts used in the design of high-performance OMVPE reactors; led the investigation and use of non-conventional chemical compounds to enable epitaxial growth of high-quality metastable antimonide-based III-Vs; and advanced the state of the art in the epitaxial growth of gallium arsenide-, gallium antimonide- and indium phosphide-based optoelectronic devices, including diode lasers, quantum cascade lasers (QCLs) and thermophotovoltaic cells. Current research is focused on the development of high-power, continuous-wave QCLs emitting in the long-wave infrared region.

Wang has authored or coauthored more than 170 publications; has been granted 8 patents; and edited one book. She has chaired and organized national and international conferences related to epitaxial crystal growth and mid-infrared materials. She is a member of the Executive Committee for American Association of Crystal Growth, the International Advisory Committee for International Conferences on Metalorganic Vapor Phase Epitaxy, and the Electronic Materials Conference Committee. She is also a Fellow of the National Academy of Inventors. She will serve as program co-chair for the next International Conference on Crystal Growth and Epitaxy in 2019.

Wang previously received the 2017 American Association for Crystal Growth Award for her contributions to epitaxial crystal growth of III-Vs and the design of high-performance OMVPE reactors.

[www.ll.mit.edu](http://www.ll.mit.edu)

[www.nae.edu/?id=204037](http://www.nae.edu/?id=204037)

## Teledyne awarded \$16.4m modification to contract for rad-hard HgCdTe-based medium- & long-wave IR sensors

Under the program 'Focused Opportunity Reaching Toward Reliable Electro-Optic Strategic Sensors' (FORTRESS), the US Air Force Research Laboratory (AFRL) has awarded Teledyne Scientific & Imaging LLC of Thousand Oaks, CA, USA a \$16,448,132 modification to contract FA9453-17-C-0037 to continue work on radiation-hardened medium- and long-wavelength infrared sensors with mercury cadmium telluride (HgCdTe)-based detector technologies that have higher performance than conventional HgCdTe photodiodes.

The contract modification tasks Teledyne with pursuing these HgCdTe detector technologies in parallel with conventional HgCdTe and III-V-based unipolar barrier infrared detectors, but grown on larger substrates.

Beginning in 2016, FORTRESS contractors are working to advance and maintain the state of the art, scientific knowledge, growth, processing and characterization capability associated with low-noise infrared sensor chip assemblies (SCAs) for US strategic space applications, such as electro-optical surveillance satellites.

Fiscal 2018 and research, development, test and evaluation; and Title III funds of \$6,750,000 are being obligated at the time of award. Total cumulative face value of the contract is \$22,381,868. The Air Force Research Laboratory at Kirtland Air Force Base in New Mexico is the contracting activity.

Work on the contract modification will be performed by Teledyne in Thousand Oaks and should be completed by 12 March 2022.

As well as Teledyne, Raytheon's Vision Systems business in Goleta, CA, USA is also a FORTRESS program partner, having been awarded a \$7,355,017 cost-plus-fixed-fee contract in November 2016 to design, grow and fabricate large-format HgCdTe infrared focal-plane array detectors with ultra-low noise and high quantum efficiency (with work due to be completed by 10 July). Also, last November Raytheon Vision System was awarded a \$19m contract modification to develop (by February 2022) more capable mid-wave infrared focal-plane arrays for persistent surveillance applications. The firm is producing larger and more resistant SCAs that can withstand bombardment by space radiation, as well as laser attacks.

[www.teledyne-si.com](http://www.teledyne-si.com)

# Marktech announces multi-wavelength emitters, detectors and LEDs for wearables

Marktech Optoelectronics of Latham, NY, USA, a designer and manufacturer of standard and custom optoelectronics components and assemblies — including UV, visible, near-infrared (NIR) and short-wavelength infrared (SWIR) emitters, detectors, indium phosphide (InP) epiwafers and other materials — has launched its dedicated product range for wearables.

Marktech says that its standard and custom emitters and detectors — in both multi-wavelength and hybrid designs and in UV, visible, infrared and short-wavelength infrared (SWIR) ranges — are routinely specified within consumer- and hospital-grade flexible, stretchable and wearable devices. Some of the most common wearable applications supported include consumer-grade fitness trackers; high-end cardiac, oxygen and blood pressure monitors; audiological diagnostic devices for detecting inner ear abnormalities and damage; non-invasive optical chemical sensing; and indoor/outdoor UV-level detection.

For wearable designs requiring more advanced onboard monitoring and detection capabilities, Marktech offers multi-wavelength

emitter-detector combinations that can be integrated into a single package along with a multi-wavelength range detector. In addition, Marktech's silicon and indium gallium arsenide (InGaAs) photodetectors may be similarly combined with its gallium phosphide (GaP) Schottky UV photodiodes, creating an expanded spectral detection range of 150–1750nm. Optoelectronics assemblies are available in plastic, ceramic and glass-to-metal (hybrid) package types. Options are also available to effectively address specialty requirements for hermetic sealing, temperature extremes and humid or moisture-rich environments.

In addition, Marktech high-brightness LEDs and LED emitters are routinely specified for wearable displays and remote physiological monitoring requirements. Standard LED emitters are offered in wavelengths of 280–1720nm, with expanded wavelengths by special request. The LED emitters can be further optimized for low power consumption. Such optimizations can result in increased wearable device battery life, while still maintaining required output levels. Operating currents of 2mA or less

are also possible. In applications requiring the incorporation of a white LED, an assortment of color temperatures and color rendering index (CRI) are available, as well as lower-profile direct-attach (DA)-type chip packages.

All design and testing of optoelectronics components and assemblies is conducted at Marktech's world-wide R&D center in Latham (Albany), where it can design, develop and test optoelectronics components to customers' standards.

Marktech says that each new wearables design draws on its own portfolio of related success stories and applies the acquired value-added expertise of lessons learned. Wearable optoelectronics components can be produced in almost any sized quantity, from prototype to OEM volumes. The firm also has the necessary full in-house capabilities to perform complete electrical and optical characteristics testing, from die-level to finished product designs, as well as complete end-to-end examinations of related components and assemblies. Wearables-specific applications engineering support is also available.

[www.marktechopto.com](http://www.marktechopto.com)

## 2019 CS ManTech

Minneapolis, Minnesota, 7–10 May

**This year's CS ManTech is in final preparation for the event at the Hyatt Regency Minneapolis on 29 April–2 May.**

**Registration is open for the workshop, conference and exhibits.**

**Visit: [www.csmantech.org](http://www.csmantech.org)**

## CST Global announces moderators for T@CST website's discussion forum categories

After launching the website [www.technologyatCST.org](http://www.technologyatCST.org) at the T@CST 'Commercializing Quantum Technology' event last November, III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Glasgow, Scotland, UK has announced the industry experts who have volunteered to moderate each of its discussion forum's six categories (established at the event as the critical enablers for commercialization). They are:

- Market Readiness — Dr Anke Lohman of ESP;
- Economics — Mark Western; technology sector manager for Scottish Enterprise;
- Technical Maturity — Dr Ole Kock, technical authority – quantum sensors at Teledyne e2v;



**November's T@CST 'Commercializing Quantum Technology' event, where [www.technologyatCST.org](http://www.technologyatCST.org) was launched.**

- Political Support — Ronnie Smith, chief executive of Lanarkshire Business Gateway;
- Industrial Environment — Stephen Taylor, CEO of Technology Scotland; and

● Talent — Richard Hogg, professor of photonics at the University of Glasgow.

"The moderators will actively participate in writing content and replying to comments on the forum," says CST Global's VP sales & marketing Euan Livingston. "They will instigate and manage debate; keep content and discussions relevant; and facilitate debate on how the critical enablers to quantum commercialization are tackled," he adds.

Although the initial T@CST event covered quantum technologies, the same moderators will also cover the Array Technology event in May and the High-Power IR technology event in November.

[www.technologyatCST.org](http://www.technologyatCST.org)

## Finisar demonstrates VCSEL arrays and diffractive optical elements for 3D sensing at Photonics West

At SPIE Photonics West 2019 in San Francisco (5-7 February), fiber-optic communications component and subsystem maker Finisar Corp of Sunnyvale, CA, USA demonstrated vertical-cavity surface-emitting laser (VCSEL) arrays used in depth-sensing applications, such as 3D facial recognition in consumer mobile devices. It also displayed its line of diffractive optical elements, demonstrating WaveSource technology, and introducing a new high-speed photodetector.

"Finisar is excited to be part of this surge in adoption of laser and optics technology for sensors in smartphones, automobiles, and smart home appliances, amongst dozens of other applications," says Craig Thompson, VP of new markets. "VCSELs are a key enabler in the broad use of 3D sensing and imaging technology, and the electronics industry is starting to recognize

this," he adds.

Demonstrations at Photonics West included the following:

- A 3D camera, utilizing VCSEL technology as the infrared (IR) source, to demonstrate 3D depth sensing. Designed by Finisar partner Gener8, the 3D camera provides an accurate, high-resolution and real-time 3D 'depth map' of the scene, allowing a consumer device or a car to see in 3D, recognize movements or 'gestures' and map objects in detail. The set-up will allow attendees to interact with the live camera;
- An active demonstration of diffractive optical elements (DOEs) that shape, steer and control the light output from a laser (e.g. VCSEL) in a 3D sensor. Finisar is showing various functions using a beam profiler;
- Finisar's WaveSource laser unit demonstrating high-speed

programmable wavelength tuning with support of a WaveAnalyzer 1500S optical spectrum analyzer;

- A display of the firm's product line of ultra-high-speed photodetectors, including a 70GHz dual-wavelength device, useful in coherent test & measurement systems and ultra-high RF output power photodetectors suitable for microwave photonics and Radio over Fiber applications.

In addition, Hao Chen, principal engineer for 3D Sensing products, gave a presentation 'Cost-effective monolithically integrated surface grating for polarization-stable VCSELs', describing a shallow semiconductor grating that has been developed as an add-on feature of Finisar's VCSEL product family for low-cost yet highly effective polarization control in a range of different sensing applications.

<http://spie.org/photonics-west.xml>  
[www.finisar.com](http://www.finisar.com)

# CST Global shortlisted in Powerful Partnerships category of Scottish Knowledge Exchange Awards

III-V optoelectronic foundry Compound Semiconductor Technologies Global Ltd (CST Global) of Hamilton International Technology Park, Blantyre, near Glasgow, Scotland, UK was shortlisted in the Powerful Partnerships category of the Scottish Knowledge Exchange Awards 2019, which recognize effective, collaborative projects between academia and business. There are six award categories, each with three, shortlisted finalists, drawn from projects involving eight Scottish universities and more than 50 industrial partners.

"Many of the business and academic collaborations shortlisted in the Scottish Knowledge Exchange Awards will have a major impact on



the economy and society," says CST Global's CEO Neil Martin. The firm's shortlisting results from its "long-term knowledge exchange partnership with the University of Glasgow, spearheaded by professor Tony Kelly," he adds. "Our partnership began in 2011 and has resulted in two Knowledge Transfer Partnerships with industrial PhD scholarships. These have helped CST Global develop new product lines in the telecommunication and datacommunication markets and made a significant contribution to

our revenue generation, as well as helping to facilitate our expansion into Asian markets."

The winners were announced at the Scottish Knowledge Exchange Awards on 21 February.

The judging panel consisted of representatives from the Scottish Funding Council, Entrepreneurial Scotland, College Development Network, Zero Waste Scotland, Scottish Enterprise, Highlands and Islands Enterprise, Scottish Government, Knowledge Transfer Network and the Interface Strategic Board, with sponsorship partners Marks & Clerk, Royal Bank of Scotland and Business Insider.

[www.CSTGlobal.uk](http://www.CSTGlobal.uk)

## II-VI showcases new products and capabilities

Engineered materials and optoelectronic component maker II-VI Inc of Saxonburg, PA, USA presented at the SPIE LASE and OPTO 2019 conferences and exhibited new products and capabilities at SPIE Photonics West 2019 (2-7 February) and at SPIE BIOS Expo (2-3 February) in San Francisco, CA, USA.

### Conference papers:

- 'Towards 300W high power laser bars' by Jürgen Müller, Rainer Bättig, Vinzenz Beer, Christian Blumer, Reinhard Brunner, Jarkko Telkkälä and Johanna Wolf of II-VI Laser Enterprise GmbH (Switzerland) in LASE 2019 — Conference 10900: High-Power Diode Laser Technology XVII; Session 2: High Power Devices I, Paper 10900-9.
- 'Optics with diamond-like-carbon overcoat (DOC) provide improved optical performance over traditional DLC films and better cleanliness than standard PVD coatings' by Stan Himelinski, Jim Bacon, Alan R. Hedges and Gregg Davis of II-VI Infrared (USA) in OPTO 2019 — Conference 10914: Optical Components and

Materials XVI; Session 11: Development of Optical Components, Paper 10914-51.

### New products & capabilities:

- Zero Pixel Shift Filters for Fluorescence Microscopy: II-VI's thin-film technology delivers filters with high transmission, steep slopes and deep out-of-band blocking, enabling next-generation fluorescence microscopes to achieve very high sensitivity.
- 405nm Lasers for Biomedical Instruments: II-VI's QOMO laser is now available at 405nm, in addition to the existing laser wavelengths of 488, 638 and 660nm. The extremely stable, low noise, optical output power enhances the measurement sensitivity of next-generation flow cytometers, enabling greater accuracy and faster measurements.
- Flat Top Beam Shaper Optics: II-VI's flat-top beam-shaper optics improve laser-based micro materials processing by converting circular laser beams with Gaussian intensity profiles to circular or rectangular beams with

highly uniform or 'flat-top' intensity profiles only a few millimeters in size. Such laser beams enable process areas to be delineated precisely and processed evenly.

- Red Lasers: II-VI's red lasers enable high-power fiber-laser systems to achieve precise alignment of multi-kilowatt infrared laser beams to the target process areas. They maintain a tightly controlled high output power of 350mW to within 2% while under the presence of up to 5W of reflected optical power.
- 22W Pump Laser Diodes: II-VI's new laser diodes achieve 22W of output power or 22% more than the existing product, enabling fiber-laser designs with fewer emitters and therefore lower cost.
- 80 Watt Pump Laser Modules: II-VI's new 80W pump laser modules with wavelength-stabilized output power enable ultrafast fiber lasers to operate with very short pulses for high-precision drilling and marking.

<http://spie.org/photronics-west.xml>  
[www.ii-vi.com/material-processing](http://www.ii-vi.com/material-processing)

## POET receives US\$26–30m offer for DenseLight Fab-light strategy targets high-volume manufacturing needs for Optical Interposer solutions and vertical markets beyond datacoms

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PIC) for the sensing and datacom markets — has signed a non-binding letter of intent (LOI) to sell its Singapore-based DenseLight subsidiary.

Key terms include a proposed cash consideration of US\$26–30m (C\$34.5–40m), including a US\$4m (C\$5.3m) earn-out provision, no-shop and confidentiality clauses, and an undertaking to enter into key operating agreements, including a preferred supply agreement and a long-term strategic cooperation agreement. Definitive transaction agreements should be signed by 15 September. The broad terms of the letter of intent and the consummation of any transaction are subject to further due diligence, the negotiation of definitive agreements and obtaining required approvals by all parties, including but not limited to the TSX Venture Exchange and a majority of POET's shareholders.

Acquired by POET in May 2016 for US\$10.5m in common stock, DenseLight has been engaged primarily in developing new sensing and datacom products, including active devices for POET's Optical Interposer platform. DenseLight's annual sales of LEDs and other light sources, along with contract engineering for third parties, has grown from \$1.9m (C\$2.5m) in 2016 to US\$3.8m (C\$5.1m) in 2018.

Since the introduction of its Optical Interposer technology in January 2018, POET's development has expanded to optical waveguide designs fabricated by its manufacturing partner based in Malaysia and on novel packaging techniques related to the Optical Interposer. As the centerpiece of its growth strategy, POET will retain ownership of all the Intellectual Property unique to the Optical Interposer. The firm is now preparing to meet high-volume manufacturing requirements for Optical Interposer-based solutions, applying the active device designs achieved at DenseLight, and exploring additional vertical

markets beyond datacoms.

"This offer, and the anticipated agreements, once completed, represent a compelling opportunity to leverage our assets and inject non-dilutive capital into POET," believes CEO Dr Suresh Venkatesan. "The deal further allows POET to pursue a 'fab-light' strategy with a less capital-intensive business model that is focused on growing the Optical Interposer business through targeted investments in the design, development and sale of vertical market solutions," he adds. "At the same time, a well-funded partner capable of making investments in both DenseLight and in additional manufacturing capacity will both support the anticipated ramp of POET's Optical Interposer and transform DenseLight into a world-class manufacturer with global market reach. In addition to being one of its potentially largest customers, we expect to remain engaged with DenseLight and its partner over the long term for the benefit of both companies."

[www.poet-technologies.com](http://www.poet-technologies.com)

### POET's DenseLight launches two 1650nm-range DFB lasers

POET and DenseLight have launched two new high-performance lasers (available for immediate delivery).

DenseLight's newest line of 1653 DFB lasers are targeted at the methane gas sensing markets. Providing human-eye-safe detection of methane using laser light provides a safer, more effective laser solution than competing detection methods, the firm says. Methane is an odourless, explosive gas and exposure to it can lead to unconsciousness or death through suffocation. Detecting its presence is critical in industrial, commercial and residential settings.

The new mid-IR indium phosphide (InP)-based lasers are available in

a narrow spectrum range of  $\pm 2\text{nm}$  (centred at 1653nm) as a chip or in a cooled butterfly package, offering a competitive price range for different detection applications. Features of 1653 DFB lasers also include: a minimum output power of 6mW; cooled operation at 25°C; and a minimum SMSR of 35dB.

DenseLight is also shipping its new high-power 1650nm FP lasers for test & measurement applications, targeted at the OTDR (optical time-domain reflectometer) market where equipment is used to detect faults and understand the losses along a given length of fiber-optic cable in networking and datacoms systems. DenseLight's 1650nm FP

lasers are used in test equipment for both in-cable manufacturing and routine maintenance of fiber-optic cables. They deliver what is reckoned to be a higher-than-market-average pulsed power performance demanded by manufacturers to enhance the dynamic range of their OTDR equipment.

For flexibility in design and performance, the lasers are available in a TO package with an aspherical lens or in a TO pigtail form. Features of the 1650 FP lasers include: 50mW pulsed (TO-pigtail); 110mW pulsed (TO-A); uncooled operation; operating temperature 0–60°C; pulsed current up to 1A.

[www.denselight.com](http://www.denselight.com)

## POET provides update on above-average trading activity

POET Technologies Inc of Toronto, Canada and San Jose, CA, USA — a designer and manufacturer of optoelectronic devices, including light sources, passive waveguides and photonic integrated circuits (PIC) for the sensing and datacom markets — has provided commentary on recent events, including the above-average trading activity in its stock.

On 4 February, POET announced that it had received and signed a letter of intent (LOI) to purchase its Singapore-based subsidiary Denselight Semiconductors (acquired in mid-2016). The non-binding letter of intent is for a cash consideration of US\$30m, including \$4m in an earn-out, with a target completion date of 15 September.

This announcement complements other news that the firm released in mid-November regarding receiving the first orders for POET Optical Interposer-based solutions from global companies targeting datacom applications, subsequent to which it provided revenue guidance for 2019 of US\$8–10m (a substantial increase over its 2018 revenue run-rate of under US\$4m).

POET's strategy is focused on its Optical Interposer, a novel platform that facilitates the co-packaging of electronics and active and passive optical components in a single chip-scale package (CSP). This strategy has been supported by other announced events over the past 12 months, including:

- an alliance with China's Accelink Technologies for information and access to optical transceiver products and markets;
- an alliance with France's Almae for the co-development of lasers and modulators;
- an alliance with SilTerra Malaysia for the manufacture of its base interposer platform;
- engagement with a global firm to validate POET's designs for 400G optical engines and components;
- product announcements from Denselight for lasers targeted at the datacom market;

- progress with internal development projects, including with:
  - active devices (InP-based lasers and detectors),
  - passive devices (dielectric waveguides and filters),
  - integration and core packaging technology (passive pick & place assembly, encapsulation and singulation),
  - flip-chip laser technology, including assembly onto the interposer with integrated thermal management, consistent with the firm's stated strategy in November to accelerate the laser development roadmap,
  - wafer-scale hermetic cap development (a key component required for telecom applications).

POET claims that the Optical Interposer offers a disruptive price model and a unique approach to chip-level integration not achieved with other technologies. It has attracted customer interest such that the firm is dedicated primarily to delivering prototypes and engaging in customer qualifications for the balance of 2019.

Meeting the challenges of rapid growth in specialized, high-tech markets requires focused investment, says POET. By pursuing a capital-efficient 'fab light' strategy, it substantially improves its ability to produce, market and sell solutions in vertical markets in datacoms and beyond. Telecom, 5G cellular, wireless access, automotive light detection & ranging (LiDAR) and direct optical interconnect integration with application-specific integrated circuits (ASICs) are all markets that need the level of photonic integration enabled by the Optical Interposer, says POET.

POET cites considerable financial advantages to adopting a fab-light strategy, especially at this stage of the company's development. Lower operating expenses reduce the time to profitability and lead to higher cash flow. Lower capital investment in equipment and facilities leaves room for focused investments in design, marketing and sales.

Access to non-dilutive debt financing or lower-cost equity all help to sustain and enhance long-term shareholder value, the firm notes.

"The elements of our strategy, which may not have been clear to our shareholders who do not have the full picture, can now come into sharper focus," says CEO Dr Suresh Venkatesan. "We have brought together several distinctly different development efforts, acquisitions of markedly different technologies, alliances with companies small and large, and talented engineers from many different countries, all for the purpose of achieving a breakthrough, disruptive platform in the Optical Interposer. Photonics industry leaders at the highest levels are beginning to take notice of what POET is doing. While we are gratified by the attention and engagement, it also means that we must move faster and more deliberately to achieve our goal for our Interposer Optical engines, not just in datacom but across several vertical market opportunities," he adds.

"Our recent announcement of the possible sale of Denselight takes us further toward the goal of focused execution of our strategy," Venkatesan continues. "There are numerous benefits to POET from the possible sale, starting with our ability to concentrate our efforts on the Optical Interposer itself, capturing all the achievements in design, process development and manufacturing that we have invested in over the past two and a half years. Having a strong relationship with well-funded global supplier of lasers and detectors, supported by a new owner that shares our vision for Denselight is a significant advantage. Further, we are now better positioned to properly finance the company, through September and beyond. A substantially stronger balance sheet will enhance our credibility with customers and fortify our efforts to penetrate new markets."

[www.denselight.com](http://www.denselight.com)

[www.poet-technologies.com](http://www.poet-technologies.com)

# CEA-Leti prototypes silicon photonics-based mid-IR optical chemical sensor for portable devices

## Coin-size, on-chip sensors combine high performance and low power consumption

In a paper 'Miniaturization of Mid-IR Sensors on Si: Challenges and Perspectives' presented at SPIE Photonics West 2019 in San Francisco (5-7 February), micro/nanotechnology R&D center CEA-Leti of Grenoble, France reported that it has prototyped a next-generation optical chemical sensor using mid-infrared silicon photonics that can be integrated in smartphones and other portable devices.

Mid-IR chemical sensors operate in the 2.5-12 $\mu$ m spectral range. In less than a decade, chemical sensing has become a key application for silicon photonic devices because of the growing potential of spectroscopy, materials processing and chemical & biomolecular sensing, as well as security and industrial applications. Measurement in this spectral range provides highly selective, sensitive and unequivocal identification of chemicals.

Leti's coin-size, on-chip, Internet of Things (IoT)-ready sensors combine high performance and low power consumption and enable consumer uses such as air-quality

monitoring in homes and vehicles, and wearable health and well-being applications. Industrial uses include real-time air-quality monitoring and a range of worker-safety applications.

Mid-IR optical sensors currently available on the market are typically bulky, shoebox-size or bigger, and cost more than €10,000. Meanwhile, existing miniaturized and inexpensive sensors cannot meet consumer requirements for accuracy, selectivity and sensitivity, says Leti. While size and price are not the most critical concerns for industrial applications, bulky and costly optical sensors represent a major barrier for consumer applications, which require wearability and integration in a range of portable devices.

"Mid-IR silicon photonics has enabled creation of a novel class of integrated components, allowing the integration at chip level of the main building blocks required for chemical sensing," says lead author Sergio Nicoletti. "Key steps in this development extend the wavelength range available from a single

source, handling and routing of the beams using photonic-integrated circuits, and the investigation of novel detection schemes that allow fully integrated on-chip sensing."

CEA-Leti's development combined three existing technologies necessary to produce on-chip optical chemical sensors:

- integrating a mid-IR laser on silicon;
- developing photonic integrated circuits (PICs) in the mid-IR wavelength range; and
- miniaturizing a photo-acoustic detector on silicon chips.

"While other R&D efforts have had similar results, our project's key achievement is the use of tools and processes typical of the IC and MEMS industries," says Nicoletti. "Our focus on the choice of the architectures and processes, and the specific linkage of the series of steps also were critical to developing this optical chemical sensor, which CEA-Leti is now realizing as demo prototypes."

<http://spie.org/photonics-west.xml>  
[www.leti.fr](http://www.leti.fr)

## Cisco completes acquisition of Luxtera

Cisco of San Jose, CA, USA has completed its acquisition of Luxtera of Carlsbad, CA, USA, a privately held fabless firm that uses silicon photonics to build integrated optics capabilities for webscale and enter-

prise data centers, service provider market segments, as well as other customers.

Cisco plans to incorporate Luxtera's technology across its intent-based networking portfolio,

spanning enterprise, data-center and service provider markets.

Cisco paid \$660m in cash and assumed equity awards for the acquisition of Luxtera.

[www.luxtera.com](http://www.luxtera.com)

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# AIM updates silicon photonics MPW performance

The American Institute for Manufacturing Integrated Photonics (AIM Photonics) — an industry-driven, public-private United States Department of Defense (DoD)-sponsored engineering technology consortium, spearheaded by the State University of New York Polytechnic Institute (SUNY Poly) — has announced a number of technical updates leading to what is reckoned to be best-in-class 300mm silicon (Si) photonics-based multi-project wafer (MPW) performance.

Complementing these developments, AIM Photonics' Si photonics process design kit (PDK) continues to advance, as a result of its library of both active and passive high-performance photonic components as well as interfaces, schematics and models for the development of optical modules and systems.

"Our best-in-class MPW offerings are a testament to our deep bench of experts and collaborators who support our more than 100 signed partners and other interested collaborators," says Dr Michael Liehr, AIM Photonics' CEO and SUNY Poly executive VP for Innovation and Technology. "Combined with our recent announcement that our multi-project wafer processing time has decreased from 130 days in 2016 to fewer than 90 days, AIM Photonics remains focused on achieving impactful, world-class quality and repeatability to drive development and commercialization of the advanced technologies that will shape our world."

AIM Photonics' MPW performance is the result of new, ultra-low-loss waveguides, featuring attenuation that is less than 0.25dB/cm and 0.10dB/cm for 220nm silicon and 220nm silicon nitride (SiN), respectively, in addition to around 1dB/facet edge coupler for both transverse electric (TE) and transverse magnetic (TM) polarization. With only 90-day fabrication time for full actives to be processed on 300mm silicon on insulator (SOI) wafers, and using the same toolset that

produces 14nm and smaller circuits, these capabilities also enable easy transfer to similar high-volume equipped foundries if needed.

The MPW also features fusion bonding of the photonic integrated circuit (PIC) and an active interposer to allow for the entire design area to be utilized for photonics or metal routing, in addition to lasers that can be soldered into pockets and deep trenches for coupling. As part of the MPW offering, AIM Photonics' passive interposer also features a 100µm-thick silicon substrate with a through-silicon-via (TSV) SiN waveguide with three front-side and one back-side metal wiring levels, in addition to pockets for laser and PIC chips, which can be flip-chip soldered in deep trenches for edge or evanescent fiber coupling.

With a comprehensive set of silicon PIC component libraries and by leveraging SUNY Poly's process capabilities, AIM Photonics' PDK now consists of more than 50 reliable photonics components, including passive components such as waveguides, edge couplers and layer transitions, in addition to active devices such as C-, C+L- and O-band photodetectors; microdisk switches and modulators; thermo-optic phase shifters and switches; and variable optical attenuators (VOAs), among others, that are verified by university and industry experts. Combined with data that can be obtained from a 14nm toolset to validate designs, this information can also help those working with AIM Photonics to achieve the desired performance.

Key features of the latest AIM Analog Photonics/SUNY PDK include:

- O-band modulation, detection and coupling support;
- C+L-band modulation, detection, filtering, switching, monitoring and coupling support;
- single- and multi-level modulation format support at 50Gbps, namely NRZ and PAM-4; and
- continued multi-vendor electronics-photonics design automation

(EPDA) support with integrated EPDA PDK flow for hierarchical design and system-level simulation.

AIM Photonics says that the combined PDK and MPW offering provides access to PIC systems for all customers, especially small- to medium-size companies, that desire a reduction in the time to market, as well as lower product development risk and investment. By incorporating design, verification and process development within the PDK, such companies can quickly and efficiently modify their designs as they simultaneously reduce their cost per gigabit.

"Companies operating within the integrated photonics space face a number of challenges as they seek to provide cost-effective, high-quality products," says Dr Douglas Coolbaugh, AIM Photonics' chief operating officer & SUNY Poly associate VP for Photonics Development. "With AIM Photonics' continually updated PDK, as well as our best-in-class, cost-effective MPW that offers a broad component library, we are thrilled to assist the industry, and especially small- and medium-sized enterprises, with the capabilities and technical expertise they require to provide innovative and timely solutions to current technological challenges."

AIM is also offering new incentives to parties interested in the most recent upcoming MPW runs. These can be requested by e-mailing [reservations@aimphotonics.com](mailto:reservations@aimphotonics.com).

AIM is leveraging SUNY Poly's facilities for three total full-build/passive MPW runs that incorporate the latest PDK, with on-demand Active/Passive PIC; Passive PIC; Passive Interposer; and Active Interposer MPW runs scheduled throughout 2019. To ensure space for all interested parties, AIM is accepting reservations for these MPW runs. Interested parties can also sign up for the 2019 runs by visiting the AIM Photonics' website.

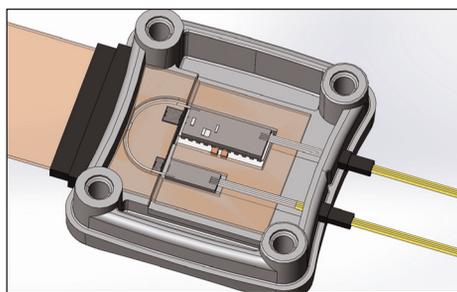
PDK and MPW fab access is solely available via MPW aggregator MOSIS.

[www.mosis.com/vendors/view/AIM](http://www.mosis.com/vendors/view/AIM)

## Rockley launches highly integrated DBR laser for high-volume sensing and imaging markets

Rockley Photonics of Pasadena, CA, USA (formed in 2013 to develop a silicon photonics platform for optical I/O in next-generation sensor systems and communications networks) has announced the availability of its high-performance and highly integrated distributed Bragg reflector (DBR) laser solution for sensing, 3D imaging and other applications that demand high-volume manufacturing.

The laser was developed as part of the firm's silicon photonics platform and designed for integration alongside other specifically developed native components such as modulators, semiconductor optical amplifiers (SOAs), multiplexors, detectors, variable optical amplifiers (VOAs) and low-loss fiber and free-space interfaces among others for highly integrated solutions. Adding to the laser's versatility is its multi-channel capability delivering numerous individually engineered and controllable beams (1, 4, 8...) from



**Rockley's multi-channel DBR laser.**

a single device. It can be specified in various wavelength grids, including the 15XX band, and with higher channel count, as required.

Its optical bandwidth in the 'eye-safe' region makes it suitable for free-space sensing applications. A narrow linewidth supports ranges over a kilometer and extremely high-resolution imaging. The laser is tunable, supporting applications with high density and broadband requirements, and it has been designed for non-hermetic packaging. As a discreet component, it is available in die or packaged formats.

"Numerous applications — from consumer electronics to vehicle sensing — are driving increasing volume demands for high-performance lasers," says CEO & chairman Andrew Rickman. "Current products on the market limit production scalability because they have to be redesigned for each sensing application and suffer from poor manufacturing tolerance. We have addressed those key scalability issues with a unified and comprehensive laser product," he adds.

Rockley says that, while its DBR laser is designed for high-volume manufacture, it does not compromise form factor or performance — characteristics that are traditionally highly dependent on the light source and means of integration.

"Our technology simplifies the manufacturing, assembly and test process while maximizing the power efficiency of the optical system," concludes Rickman.

[www.rockleyphotonics.com](http://www.rockleyphotonics.com)

## Infinera appoints former Oclaro CEO Dougherty to board

Infinera Corp of Sunnyvale, CA, USA, a vertically integrated manufacturer of digital optical network systems incorporating its own indium phosphide (InP)-based photonic integrated circuits (PICs), has appointed Greg Dougherty to its board of directors.

The firm says that Dougherty has a proven track record of executive leadership and extensive experience in the optical communications industry, along with strong operational expertise in the development of innovative optical component products and technologies.

"Greg's deep industry knowledge and expertise will be invaluable as we move forward with a broader set of end-to-end solutions, greater scale and expanded relationships with the world's leading network operators," comments chairman

Kambiz Hooshmand. "His insights and guidance will be tremendous assets."

Dougherty was a director of intelligent photonic solutions provider Avanex Corp from April 2005 to April 2009, when it merged with Bookham to become Oclaro. At Oclaro, he was a director from April 2009 and simultaneously CEO from June 2013 until the firm's acquisition by Lumentum last December.

Dougherty also served as a director of Picarro Inc (a manufacturer of ultra-sensitive gas spectroscopy equipment using laser-based technology) from October 2002 to August 2013, and as its interim CEO from January 2002 to April 2004. Previously, Dougherty was chief operating officer at SDL from 1997 to 2001, when the firm was acquired by JDS Uniphase Corp,

where he continued in the role until 2002. From 1989 to 1997, Dougherty was director of product management & marketing at Lucent Technologies Microelectronics in the Optoelectronics Strategic business unit.

"I look forward to working closely with Tom and the entire Infinera leadership team at a time when the company's distinguished heritage of innovation puts it in a unique position to redefine transport networks for a new generation of communications services," says Dougherty.

It was also announced that John P. Daane, a member of Infinera's since January 2016, will not stand for re-election at the upcoming 2019 annual meeting of stockholders.

[www.infinera.com](http://www.infinera.com)

# Rockley completes silicon photonics platform

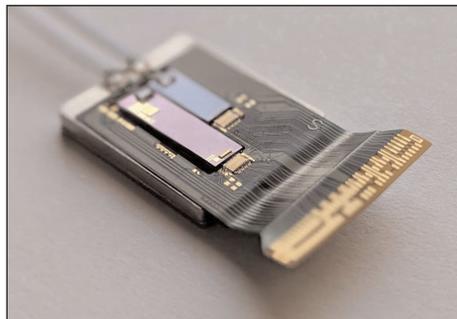
Rockley Photonics of Pasadena, CA, USA (formed in 2013 to develop a silicon photonics platform for optical I/O in next-generation sensor systems and communications networks) has announced the completion of its fully integrated silicon photonics platform running in a large-scale foundry environment.

Rockley says that it has overcome significant technological challenges that have, until now, held back the broad adoption and implementation of integrated photonics in high-volume applications. Chip-set shipments to customers have begun, and products implementing them will ramp up the production curve.

Delivering low-cost, high-value wafer-scale processing, the integrated photonic platform is key to product opportunities in applications where Rockley has go-to-market partnerships including optical sensing, 3D laser imaging and artificial intelligence (AI) computing connectivity. It is said to solve the key issues experienced by wafer-scale silicon photonics to date, including the elimination of active precision fiber alignment, full functionality in a single chip and optimized integration with micro-electronics and systems.

"In one partnership example, active optical cables (AOCs) and transceivers will be manufactured by our joint venture with Hengtong Optic-Electric Suzhou, a world-leading optical fiber and cable provider," says chairman & CEO Andrew Rickman. "The platform-derived photonics and electronics chip-set we are providing are key to facilitating the massive scaling required in data-center expansion, AI computing connectivity and 5G backhaul, where high bandwidth and dense optical input/output are paramount and also where cost and power utilization are critical," he adds.

High-density in-package optical connectivity for powerful application-specific integrated circuits (optoASICs) — integrating optical connectivity directly with digital



**Rockley's transmit-receive optical sub-assembly (TROSA) for data communication AOCs and transceivers.**

silicon CMOS within the same package — is one of the applications for which Rockley's versatile technology platform has been developed. At last March's Optical Fiber Communications conference (OFC 2018), Rockley demonstrated this technology in what was claimed to be the first single-ASIC Level 3 data-center routing switch with integrated 100G network ports using single-mode optical fiber.

"The platform's ability to fully integrate transceiver functionality sets it apart from other transceiver solutions that use older chip-on-board, labor-intensive assembly practices," says Rickman. "Its versatility provides the pathway for the vertical integration of a low-cost, differentiated product set that will help drive new competitiveness in large established markets like the AOC/transceiver market as data links reach 400G and beyond."

Rockley's wafer-scale platform includes the following functional blocks:

- Lasers — Multiple laser types (including back reflection tolerant and ultra-narrow linewidth) can be multi-channel and tunable, with good power efficiency over a wide optical bandwidth.
- Detectors — High-performance detectors for direct and coherent applications (including sensing and 400G communications).
- Modulators — Ultra-compact amplitude and phase modulators (which are power efficient, high speed and capable of handling a

broad range of wavelengths for sensing and 400G applications).

- Free-space optics — The platform allows for efficient light coupling from free space into and out of the photonics circuits, with either edge or perpendicular coupling (enabling a broad range of 3D consumer-sensing applications).

- Fiber-optic coupling — Where needed, the photonic IC contains on-chip embedded ultra-efficient interfaces to optical fibers via single-step passive fiber-array attachment (allowing the fibers to be attached directly to the photonic IC without need for costly single-fiber active alignment process steps).

- Complex optical signal processing (waveguide circuits) — Optical circuits that are low loss, polarization maintaining and athermal for optical signal processing, CWDM/DWDM (coarse and dense wavelength-division multiplexing), coherent and high-resolution beam shaping, scanning and steering.

- Photonic integrated circuits — The platform enables integration of light sources, semiconductor optical amplifiers (SOAs), active devices, passive devices and optical coupling elements into a single silicon device (covering a wide optical band suitable for connectivity and sensing applications).

- Wafer-scale processing — The platform enables high-throughput wafer-scale processing of monolithic and multi-die structures (including chip-on-wafer integration).

- Interface electronics (ICs) — Rockley says that its electronics team has expertise in designing and delivering efficient and high-performance analog and mixed-signal ASIC blocks together with application-specific digital interfaces. The platform includes 2D and 3D packaging of photonics ICs with ASICs.

[www.rockleyphotonics.com](http://www.rockleyphotonics.com)

# Lumentum's revenue suppressed by faltering 3D sensing laser demand, but telecoms demand outstripping capacity expansion

## Margins diluted by Oclaro acquisition, but synergies to outweigh revenue loss from paring low-margin products

For its fiscal second-quarter (to 29 December 2018), optical and photonic optical component and subsystem maker Lumentum Holdings Inc of Milpitas, CA, USA has reported revenue of \$373.7m, down 7.6% on \$404.6m a year ago but up 5.5% on \$354.1m last quarter. However, results include \$29.6m from 20 days of revenue from Oclaro Inc of San Jose, CA, USA (which provides components, modules and subsystems for optical communications) since the closing of its acquisition on 10 December (after receiving anti-trust approval from China, and nearly nine months after announcing the acquisition). Excluding Oclaro, revenue was within the revised guidance range of \$335–355m given on 12 November (albeit below the original guidance of \$405–430m given on 1 November).

Optical Communications segment revenue was \$325.4m (87.1% of total revenue), up 4.9% on \$310.1m last quarter but down 9.6% on \$360.1m a year ago. Of this:

- Telecom revenue was \$172.5m, up 21% on \$142.9m last quarter and 57% on \$110.2m a year ago, driven primarily by strong growth in ROADMs (up 29% quarter-on-quarter and 110% year-on-year) plus the 20 days of contribution from Oclaro's telecom product lines. "Strength in demand and manufacturing capacity expansions drove ROADM and fiber lasers to new record levels," notes president & CEO Alan Lowe. "Our investments in new and differentiated products continue to drive growth in our telecom and lasers product lines."

- Datacom revenue was \$33.4m, down 2% on \$34.2m last quarter (it had been expected to be down 20–30%, but that was offset by the acquired Oclaro datacom revenue).

"We continue to be selective in our sales of transceivers in this margin-challenged product area while we develop our lower-cost 100G and next-gen 400G products," says Lowe.

- Industrial & Consumer revenue was \$119.5m, down 9.8% on \$133m last quarter and 45% on \$215.5m a year ago, driven by softer demand for 3D sensing lasers. On 12 November, Lumentum had announced "a request from one of our largest Industrial & Consumer customers for laser diodes for 3D sensing to materially reduce shipments to them" (Apple contributed 30% of Lumentum's total revenue in fiscal full-year 2018).

Commercial Laser segment revenue was \$48.3m (12.9% of total revenue), up 9.8% on \$44m last quarter (whereas it had been expected to be flat), driven by growth in fiber-laser sales. "We benefited from capacity expansion and further ramped volumes of our newest fiber-laser products to meet strong customer demand," says Lowe.

"We again achieved record revenue from our kilowatt-class fiber lasers, which grew 12% sequentially and 133% relative to the prior year."

On a non-GAAP basis, gross margin has fallen further, from 44.9% a year ago and 40.3% last quarter to 40.1%, due mainly to the product mix (as well as some dilution from Oclaro, which had been running below 40%). Specifically, Optical Communications gross margin has fallen from 45% a year ago and 40.3% last quarter to 39.7%, due to the lower Industrial & Consumer revenue (3D sensing lasers) in the mix. Commercial Lasers gross margin was 42.7%, down from 44.7% a year ago but up from 40.2% last quarter due to higher volumes and product cost reductions.

Operating expenses have risen from \$57.9m (16.4% of revenue) last quarter to \$67.5m (18.1% of revenue). However, the R&D expenses of \$39.3m included not only increased investment in new product development but also the added R&D expense from Oclaro.

Operating margin has fallen further, from 28.3% a year ago and 23.9% last quarter to 22% (well below the expected 28–30%), again due to the faltering 3D sensing laser sales.

Likewise, net income has fallen further, from \$107.8m (\$1.67 per diluted share) and \$85.8m (\$1.31 per diluted share) last quarter to \$78.3m (\$1.15 per diluted share, below the expected \$1.60–1.75).

The cash portion of the Oclaro acquisition was \$964.8m, funded by a new term loan of \$500m plus the combined company's balance sheets, which at the end of the December quarter totaled \$1.1bn. After paying the \$964.8m plus more than \$50m in acquisition-related fees, Lumentum's cash and short-term investments fell by only \$50.2m during the quarter, from \$734.3m to \$684.1m, due to its strong cash generation.

"The closing of the Oclaro acquisition in December gives us a first-mover advantage in a consolidating industry and establishes leadership positions based on fundamental photonic chip capabilities across a broad range of products and technologies to address the growing communications, industrial and consumer markets," reckons Lowe. "With the closing of the acquisition, we now have chip sales in the datacom and 5G markets, which we expect we will continue to grow," he adds.

"Demand from our customers for our telecom products is very strong and is spread across a broad customer and geographical base," says

Lowe. "Strength in Telecom demand is expected to continue in the third quarter, counter to historical seasonality," he adds. "We continue to add ROADM capacity, but demand will outstrip our ability to supply throughout the third quarter."

For fiscal Q3/2019 (including a full quarter from Oclaro), Lumentum expects revenue to rebound to \$420–440m. However, operating margin will fall to 16–18% and diluted earnings per share to \$0.76–0.94.

Specifically, Commercial Lasers segment revenue will rise, due mainly to new product growth. In the Optical Communications segment, Telecom revenue will rise, driven by continued market growth plus a full quarter of the Oclaro acquisition. Datacom revenue will also rise (significantly, to \$50–55m), but this will only be due to the full quarter of the acquisition — compared to combined company historic levels, Datacom revenue will decline. Industrial & Consumer revenue will fall due to consumer electronics customer seasonality (the firm is still taking a conservative approach to 3D sensing laser revenue).

"The market for laser-based sensing is still in its infancy," notes Lowe. "We continue to make excellent progress with additional Android customers and additional new design wins. During the second-half calendar 2018, additional customers announced or started shipping high-

end 3D sensing enabled devices. During calendar 2019, based on customer engagements we have today, we expect new and existing customers will announce and release additional new 3D sensing enabled products. Several of these opportunities are expected to bring new functionality that could expand our content per device, including world-facing capabilities... These new customer products are the first step to broad incorporation of 3D sensing in lower-priced, higher-volume devices in the years to come. The market opportunity over the long run is tremendous, as the applications that use our lasers enhance security, safety and new functionality in the billions of electronic devices that people rely on every day. The seeds for this long-term market opportunity continue to be planted."

"We are making healthy investments in new laser product development and production capacity, targeting higher-growth material processing applications in calendar 2019, and over the long run we have good opportunities for growth, driven by new product design wins in addition to market growth," reckons Lowe.

Synergies from the Oclaro acquisition should be in excess of \$60m per year, within 12–24 months from the close of the transaction. "To date, we estimate that we have achieved more than \$10m in annual expense synergies," says

interim chief financial officer Chris Coldren. "We expect modest level of new synergies to be obtained in the third quarter and then we expect synergy attainment will accelerate in the fourth quarter and into fiscal year 2020. Work done since the closing of the transaction gives us confidence in our ability to meet or exceed our expense reduction target," he adds. "We are going through the product rationalization as well as fab utilization optimization and we'll be talking to our customers later this quarter and putting in place the actions to drive to the lowest-cost product or the highest-margin product, where appropriate, where there is overlap. But the overlap is pretty minimal and we expect to drive those to conclusion throughout this calendar year."

Such product rationalization could eliminate over \$50m of revenue through paring of product lines, concedes Coldren. However, "Expense synergies did not include any increased revenue or profit due to new product differentiation or product roadmap acceleration resulting from the combined company's innovation engine [aiming for this to more than offset the loss of revenue to product paring]. However, we believe over the long run, it is these types of synergies that will create the most long-term value and underpins our strategic rationale for the transaction."

## Lumentum appoints Wajid Ali as chief financial officer

Lumentum has appointed Wajid Ali as executive VP & chief financial officer. He will also serve as principal financial officer, replacing Christopher Coldren, who had been serving as interim CFO since June.

Lumentum says that Ali has extensive financial management expertise and a deep knowledge of the technology industry. He joins from Synaptics Inc, where he was senior VP & chief financial officer. Previously, he was VP & controller of Teledyne Technologies, after having been CFO at DALSA Corp, a

public semiconductor firm acquired by Teledyne in 2011. He also held financial management positions at AMD and ATI, overseeing finance functions for large business groups.

Ali has a Masters of Business Administration from the Schulich School of Business, York University, Master and a Bachelor of Arts degrees in Economics from York University, and CPA and CMA designations from Chartered Professional Accountants of Ontario, Canada.

"His background — most recently with Synaptics, Teledyne Technolo-

gies as well as DALSA — uniquely qualify him to lead our finance team as well as to help drive the company to the next level of performance," comments president & CEO Alan Lowe. "Wajid will hit the ground running, especially when it comes to the integration efforts of our recent Oclaro acquisition," he adds.

"It is an exciting time to join the company, with the recent acquisition and the opportunity to capitalize upon the strengths of the newly combined company," comments Ali.

[www.lumentum.com](http://www.lumentum.com)

## Source Photonics opens new laser fab and transceiver assembly facility in China

### Expansion to meet growing demand in rapidly evolving data-center and 5G markets

Source Photonics Inc of West Hills, CA, USA (which provides optical connectivity products for data centers, metro and access networks) has confirmed the opening of its new fabrication facility in Jintan, China, to support its global growth, enhancing what is reckoned to be an advantage in the optical communications industry in which most manufacturers are fabless.

The new fab will double the firm's capacity of indium phosphide (InP) lasers and related components and will augment its existing fab in Hsinchu, Taiwan, which has itself doubled its output over the past three years.

Constituting a total investment of over \$50m, the new Jintan fab includes a fully integrated laser chip production capability, high-prec-

sion TO operations, and an R&D facility to support the firm's global technology roadmap and regional customers. Its chip capabilities include base wafer, regrowth and chip processing, while its TO operations will support the requirements emerging for high-speed PON and 5G markets.

This investment follows recent expansions at the facility in Hsinchu (which has over 20 years experience in laser production) including significant expansion in metal-organic chemical vapor deposition (MOCVD) and advanced coating technologies. The Taiwan facility also recently completed expansions to support transceiver assembly in support of customers' demands for resiliency in their supply chains.

"These new investments support

our integrated manufacturing approach, which is critical to meeting the ever-growing needs of our customers," says CEO Doug Wright. "Managing the entire value chain from laser production through transceiver assembly gives Source Photonics differentiated capability that enhances speed to market, yields manufacturing innovations, and offers flexibility our customers demand," he adds.

The new facility includes R&D and reliability labs and is fabricated in accord with the firm's proprietary Source Management System (SMS), which is built around Lean practices. Environmental controls include a zero-discharge waste treatment capability that meets the highest standards in environmental stewardship, the firm says.

## Source Photonics raises over \$100m in funding to support growing data-center and 5G business

To further increase the scale of its operations in order to support its growing data-center and 5G business, Source Photonics has closed more than \$100m in equity funding from new financial and strategic investors that will be used for growth investments.

LightCounting reported that sales of optical components and modules to cloud companies grew by 63% in 2016 and 64% in 2017, and will average about 20% annually through 2023. Higher growth rates in 2020-2022 will be driven by the first volume deployments of 400 Gigabit Ethernet (400GbE) as a result of the rise of 5G and the cloud, the market analyst firm adds.

Planned developments include the creation of a new laser fab, upgrades to existing production facilities and increased investment

in the R&D of next-generation technologies.

"Exciting new applications such as the Internet of Things (IoT), virtual reality (VR) and cloud services are growing in popularity every day," notes CEO Doug Wright.

"These applications all depend on the next standard of connectivity, and 5G depends on the backing of a world-class optical network... Our investors have shown this confidence in us and are confident that the investment will support our ongoing work to enable the next era of connectivity."

Upgrades to Source Photonics' fab in Taiwan have already been completed and production operations have begun for a new fab in Jintan, China, using the latest funding. The funding will also be used towards technology investments

for advanced coating technologies to enable next-generation lasers and transceivers for the fast-growing 5G and data center markets.

Source Photonics' latest range of technology is being exhibited at the Optical Networking and Communication Conference & Exhibition (OFC 2019) in San Diego, CA, USA (4-7 March). Products on display include its new 400G-LR8 and DR4 QSFP-DD solutions, which are the latest addition to its PAM4-based optical transceivers portfolio. Other products showcased include several QSFP28 solutions such as the 100G-DR/FR, 100G-SR4, 100G CWDM4, and 100G-LR4. The firm is also demonstrating some of its solutions for the 5G market, such as the 50G-ER QSFP28 and 25G LAN DWM SFP28.

[www.sourcephotonics.com](http://www.sourcephotonics.com)



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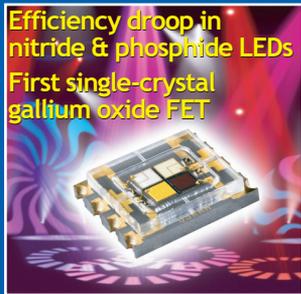
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# Emcore's quarterly revenue falls 4.9% to \$24m

## Margins recovering as chip sales rise and production costs of new L-EML transmitters decline

For its fiscal first-quarter 2019 (to 31 December 2018), Emcore Corp of Alhambra, CA, USA — which provides indium phosphide (InP)-based optical chips, components, subsystems and systems for the broadband and specialty fiber-optics markets — has reported revenue of \$24m, down 4.9% on \$25.2m last quarter and level with \$24m a year ago.

The Navigation segment remained flat, at 10% of revenue, although the firm says it continued to make progress in both production contracts as well as product development initiatives for new programs.

Chip sales rose from 10% to 18% of total revenue, driven by growth in demand in both 2.5 GPON products in China and non-GPON-related products.

Broadband comprised 72% of total revenue, down from 80% last quarter — which had included a large order for L-EMLs (linear externally modulated lasers) — as the cable TV market returned to a more normalized demand environment (falling from 71% to 62% of revenue in fiscal Q1).

Demand for CATV products was hence split between legacy distributed feedback (DFB) products and L-EML products, as expected (a natural consequence of returning to normalized inventory levels of legacy products in the fiscal fourth quarter, resulting in normal production splits between laser modules and L-EML transmitters in Q1).

"Demand for our new L-EML products continued to be strong," says president & CEO Jeffrey Rittichier. "Our L-EML product line continues to perform beyond expectation, including production shipments of the design wins that were previously announced."

Non-CATV broadband products (Satcom video & wireless) remained steady quarter-over-quarter, with Satcom nominally up.

"Revenue in our first fiscal quarter of FY19 met expectations, as did the sequential improvement in gross margin," says Rittichier.

On a non-GAAP basis, gross margin was 24.7%, up from 18.1% last quarter (due to stronger factory loading and a favorable product mix). "Improved operational performance over the quarter helped drive margins upward, despite slightly lower volume," says Rittichier. However, gross margin was down from 33.6% a year ago. "This transition to L-EML has generated near-term costs in three areas: production immaturity; the secondary impact of L-EML products on excess and obsolete (E&O) charges; and improvements in standard cost, which drive balance-sheet changes that ultimately affect the profit & loss."

Operating expenses have risen further, from \$8.7m a year ago and \$10m last quarter to \$11.6m. R&D investment in Navigation products fell slightly due to the timing of project material expenses, while sales, general & administrative (SG&A) expenses rose (from \$5.5m last quarter to \$7.6m) due to an increase in consulting and litigation-related expenses.

Driven by the improved gross margin performance, pre-tax loss from operations has been cut further, from \$3.3m

(-\$0.12 per diluted share) last quarter to \$2.4m (-\$0.09 per diluted share), although this compares with a profit of \$0.7m (\$0.03 per diluted share) a year ago.

**We are continuing to optimize the geographic footprint of our electronics manufacturing services supply chain to increase the leverage that we have with suppliers and to minimize any tariff impacts**

Capital expenditure (CapEx) remained \$2.8m. Depreciation was \$1.6m. During the quarter, cash and cash equivalents (including restricted cash) hence fell by \$5.8m to \$57.3m.

"The overall decline in cash was in line with our expectations for the quarter, as we continue to invest in our fab and modernize our campus," notes interim principal financial & accounting officer Mark Gordon.

"We expect to continue the modernization of our wafer fab equipment and physical plant to improve our ability to build 25G-and-beyond products as well as chip-level products across multiple material systems," says Rittichier.

"We embarked on a general campus upgrade that was long overdue and we'll complete this in phases over the next two years or so. This will allow us to recover significant amounts of space which was poorly organized in the original buildout of the Alhambra facility. This will also enable us to produce more products in Alhambra and will significantly improve manufacturing asset utilization," he adds.

"We are continuing to optimize the geographic footprint of our EMS [electronics manufacturing services] supply chain to increase the leverage that we have with suppliers and to minimize any tariff impacts," says Rittichier. "The tariff situation is fluid but, given what we know today, we don't expect a material impact from changes in the short-term and feel that we have a solid strategy for staying ahead of the issue."

For fiscal second-quarter 2019 (to 31 March), Emcore expects revenue to fall to \$21–23m, taking into account the traditional weather-related seasonal softness in cable TV demand, coupled with the impacts of Chinese New Year, offset by expected growth in all non-CATV product revenue.

"The rapid acceptance of the L-EML

has caused us to have to take unplanned impairment charges for the internally competitive technologies such as externally modulated transmitters and DFB lasers," says Rittichier. "We see those charges coming down in the current quarter, but will see those improvements moderated somewhat due to under-absorption caused by the traditional soft cable TV cyclicality in the winter and Chinese New Year," he adds.

"We've been executing on our margin improvement plan for nearly two quarters and are seeing the results that we were expecting,"

comments Rittichier. "Costs are coming down as planned, and we expect to see the benefits of this after the current inventories are turned over in the coming months. While there's still work to be done to improve gross margins overall, our progress in this area is on track," he adds.

"Looking beyond Q2, we do expect to see improvement in gross margin, as we continue to increase chip contribution and see the production cost of our L-EML-based transmitters decline," says Gordon. "As is typical of new products when first introduced, our L-EML transmitters are

working down the manufacturing cost experience curve as projected, leading to stronger gross margins on this product line in the quarters ahead."

"Finally, the improvements that we've made in standard cost caused capitalized variances in inventory over the past few quarters that are now rapidly declining," says Rittichier. "As a result, we expect to see continual improvement in gross margin throughout the second half of fiscal 2019, as costs associated with these areas return to normal levels."

[www.emcore.com](http://www.emcore.com)

## France's Sofradir and ULIS investing €150m in French Nano 2022 program as part of EU's IPCEI initiative on microelectronics

### Five-year investment to develop next-generation infrared detectors

France's Sofradir of Palaiseau (near Paris), which develops and manufactures infrared (IR) detectors for military, space, scientific and industrial applications, and its subsidiary ULIS of Veurey-Voroize (near Grenoble) are participating in the Nano 2022 initiative.

This follows the European Commission's approval on 18 December of the 'Important Project of Common European Interest' (IPCEI), a joint project by France, Germany, Italy and the UK to give €1.75bn (\$2bn) in public support for research and innovation in microelectronics.

Nano 2022 is France's initiative within the cross-border program that will support developments in nanotechnology (a market sector of strategic importance for the future that includes applications such as smart sensors). The Auvergne-Rhone-Alpes region, where Sofradir and ULIS have operations, is contributing €35m (\$40m) to support Nano 2022.

Sofradir makes cooled infrared (IR) detectors based on mercury cadmium telluride (MCT/HgCdTe), indium antimonide (InSb), quan-

tum-well infrared photodetector (QWIP) and indium gallium arsenide (InGaAs) technology. ULIS makes uncooled IR sensors based on amorphous silicon.

Sofradir and ULIS, whose infrared technologies are used in applications ranging from space observation and environmental monitoring to security surveillance and predictive maintenance, will invest €150m (\$171m) over 2018-2022 in the Nano 2022 initiative in order to develop next-generation infrared detectors.

"Infrared technologies can offer the necessary solutions for improving assisted living, mobility, energy efficiency, security and environmental monitoring, which are all crucial societal needs," says Jean-François Delepau, chairman & CEO of Sofradir and ULIS. "As a result of our investment, equipment manufacturers will benefit from the ease-of-use and performance these new products will offer."

Nano 2022 will enable ULIS to develop the next generations of infrared detectors to address trends in autonomous systems for smart buildings (workspace management,

energy savings), road safety and in-cabin comfort of vehicles. It also enables Sofradir to develop the very large dimension infrared detectors needed for space and astronomy observations as well as compact and light sensors that can be used in portable devices and on drones. Nano 2022 contributes to the funding of the pilot lines required for developing these technologies and products.

Sofradir and ULIS are participating in Nano 2022 alongside other companies based in the Auvergne-Rhone-Alpes region, including STMicroelectronics and Soitec.

The IPCEI framework develops key cross-border R&D and infrastructure projects aimed at encouraging member states to channel their public spending into large projects. These aim to make a contribution to economic growth, job creation and the competitiveness of Europe. The European Commission (DGComp) evaluates the funding conditions, ensuring they are in line with EU state aid rules.

[www.sofradir.com](http://www.sofradir.com)

[www.clustercollaboration.eu/tags/ipcei](http://www.clustercollaboration.eu/tags/ipcei)

## 5N Plus supplying substrates to SolAero

Specialty metal and chemical products firm 5N Plus Inc of Montreal, Québec, Canada says that its US-based subsidiary 5N Plus Semiconductors has been awarded a multi-year program to supply substrates to SolAero Technologies Corp of Albuquerque, NM, USA (formerly the Space Photovoltaics business of Emcore, making high-efficiency solar cells and panels) for satellite solar arrays for applications including powering a constellation of several hundred low-orbit broadband satellites being manufactured by OneWeb Satellites (a joint venture between OneWeb and Airbus). This network of satellites will provide global, persistent, low-latency internet access.

Fiber-quality broadband connectivity from low-orbit satellites is an emerging market enabled by numerous rapid technological advances in satellite manufacturing, notes 5N. Not only does this offer the possibility to reach an estimated 3.5 billion people under-served by existing telecom networks but it also pro-

vides a new dimension of flexibility and freedom for mobile connectivity, internet of things and M2M (machine-to-machine) applications, the firm adds.

Production of the satellite constellation will begin in 2019, with the balance of the program to be delivered by 2021. Considering the requirement to periodically replace satellites on orbit and additional constellation programs being in various stages of planning, demand from this segment of the space market is expected to grow in the coming years.

5N Plus provides purified metals such as bismuth, gallium, germanium, indium, selenium and tellurium, and also produces related II-VI semiconducting compounds such as cadmium telluride, cadmium sulphide and indium antimonide as precursors for the growth of crystals for solar, LED and eco-friendly materials applications.

But in recent years 5N Plus has expanded its portfolio of specialty

semiconductors to include wafer-level products based on the III-V and II-VI families of materials. These address several growth markets, including medical imaging, sensing, security, surveillance and renewable energy in both space and terrestrial applications. Last year, the firm announced that it would double the capacity of its semiconductor plant in Montreal to keep pace with growing market demands.

"The close partnership between 5N Plus and SolAero Technologies has been an essential element in transforming an ambitious plan into reality," says 5N Plus' president & CEO Arjang Roshan.

"OneWeb is leading the way in a transformation of the satellite telecommunications industry and relying on strong partnerships throughout the value chain to make this program successful," says SolAero's chairman & CEO Brad Clevenger.

[www.5nplus.com](http://www.5nplus.com)  
[www.solaerotech.com](http://www.solaerotech.com)

## First Solar's Q4 sales more than double year-on-year

First Solar Inc of Tempe, AZ, USA — which makes thin-film photovoltaic modules based on cadmium telluride (CdTe) as well as providing engineering, procurement & construction (EPC) services — has reported full-year net sales of \$2244m for 2018, down 23.7% on \$2941m for 2017.

However, fourth-quarter net sales were \$691m, up 2.2% on \$676.2m last quarter (due mainly to the sale of certain projects in Japan) and more than doubling from \$339.2m a year ago.

Operating expenses have risen from \$70.7m last quarter to \$87.3m.

Net income was \$52.1m (\$0.49 per diluted share), down from \$57.8m (\$0.54 per diluted share) last quarter. Full-year net income was \$1.36m (\$1.36 per diluted share) for 2018.

Due mainly to capital investments in Series 6 manufacturing capacity,

factory ramp activities, and the timing of cash receipts from certain systems project sales, cash and marketable securities fell during the quarter from \$2.7bn to \$2.5bn. Net cash balance (cash and marketable securities minus expected debt at the end of 2018) was \$2.1bn.

"We had a number of notable accomplishments in 2018, including strong net bookings of 5.6GW<sub>DC</sub> and the start of Series 6 [module] production at three factories," says CEO Mark Widmar. "Our Series 6 progress in 2019 continues to be encouraging, with the start of production at a fourth factory, and ongoing improvements in throughput and efficiency at our existing facilities," he adds. "We continue to see good demand for Series 6, and our pipeline of contracted shipments positions us well for the year."

First Solar's year-to-date net book-

ings in 2019 so far are 1.3GW<sub>DC</sub>.

To reflect lower expected operating expenses (associated primarily with a decrease in expected production start-up costs from \$90–100m to \$75–85m), full-year 2019 guidance for OpEx has been reduced from \$390–410m to \$375–395m. Due to expected increases in production ramp costs (from \$20–30m to \$35–45m), gross margin guidance has also been lowered, from 20–21% to 19.5–20.5%. These adjustments offset each other, so there are no changes to the associated guidance ranges for EPS (\$2.25–2.75) and net cash balance (\$1.6–1.8bn).

Full-year 2019 guidance is unchanged for shipments (5.4–5.6GW), net sales (a rise to \$3.25–3.45bn) and capital expenditure (\$650–750m).

[www.firstsolar.com](http://www.firstsolar.com)

## Midsummer hires new head of module R&D

To further strengthen its team, Midsummer AB of Järfälla, near Stockholm, Sweden — a provider of turnkey production lines as well as flexible, lightweight copper indium gallium diselenide (CIGS) thin-film solar panels for building-integrated photovoltaics (BIPV) — has hired Klaus Wiegel as a new head of module R&D (from 1 March), responsible for the development of next-generation flexible solar panels.

The firm says that it is experiencing greater global interest in its flexible solar panels (especially in the USA, where demand for new



**Klaus Wiegel.**

types of flexible solar cells is increasing), so it is currently expanding its in-house production of solar cells and flexible panels. Wiegel has a background as research & production manager at Gällivare Photovoltaic (GPV) and most recently was research engineer and former production manager at Swedish mining giant LKAB. He also has a

Master of Science (MSc) in Physics from Germany's Technical University of Dresden.

"Wiegel, with his extensive experience from both research and production of solar modules, will be a good addition as we intend to turn up our production rate further to meet the increased demand for our products," says CEO Sven Lindström.

Midsummer claims that its DUO system is the world's most widespread manufacturing tool for flexible thin-film solar cells.

[www.midsummer.se](http://www.midsummer.se)

## Life cycle assessment reveals minimal carbon footprint from Midsummer's CIGS solar cell production

A new study commissioned by Midsummer (and reviewed and approved by Swedish independent third-party institute Miljögiraff AB) shows that its proprietary flexible copper indium gallium diselenide (CIGS) thin-film solar module manufacturing process is much more environmentally friendly than other solar module production processes (such as those for silicon-based solar modules).

The objective of the life-cycle assessment (LCA) study by Swedish industrial research institute Swerea IVF was to understand the environmental impact of Midsummer's production method for flexible CIGS solar module in a life-cycle perspective. The results

showed much lower CO<sub>2</sub> emission compared with not only similar modules made of silicon but also other thin-film technologies. Compared with the production of silicon solar modules, the rapid sputtering production process for thin-film solar modules can result in a global warming potential (GWP) of just 1/10 of the silicon modules, it is reckoned.

"As solar energy installations spread globally, there will be an increased focus on its carbon footprint and energy payback," says Midsummer's CEO Sven Lindström. "To manufacture energy-demanding silicon panels, glass and aluminium frames with dirty coal power is not environmentally friendly," he adds.

"PV suppliers will be increasingly judged on the climate effect of their production processes. Here, Midsummer has a clear advantage with its extremely small carbon footprint. Our manufacturing process is very energy efficient and we don't use silicon, glass or frames."

Another reason for the low carbon footprint is the extremely thin light-absorbing CIGS layer. Midsummer uses less than 1µm of CIGS materials in its production process, enabling not only a fast production process but also low energy consumption.

[www.midsummer.se/products/duo-turnkey-system](http://www.midsummer.se/products/duo-turnkey-system)

[www.swerea.se/en](http://www.swerea.se/en)

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# Monolithic indium arsenide antimonide on silicon mid-IR photodetector

**Low-cost ultra-compact systems could find ready deployment in gas sensing, defense and medical diagnostics.**

Lancaster University and University of Warwick in the UK have monolithically integrated indium arsenide antimonide (InAsSb) mid-infrared (MIR) photodetectors on silicon [Evangelia Delli et al, *ACS Photonics*, 2019, volume 6 (issue 2), p538]. The devices used a 'type-II' structure with an aluminium gallium arsenide antimonide  $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}_{0.1}\text{Sb}_{0.9}$  electron-blocking barrier sandwiched between n-type InAs/InAsSb superlattices (SLs) to give an 'nBn' band structure that presents a barrier to electrons and a well to holes.

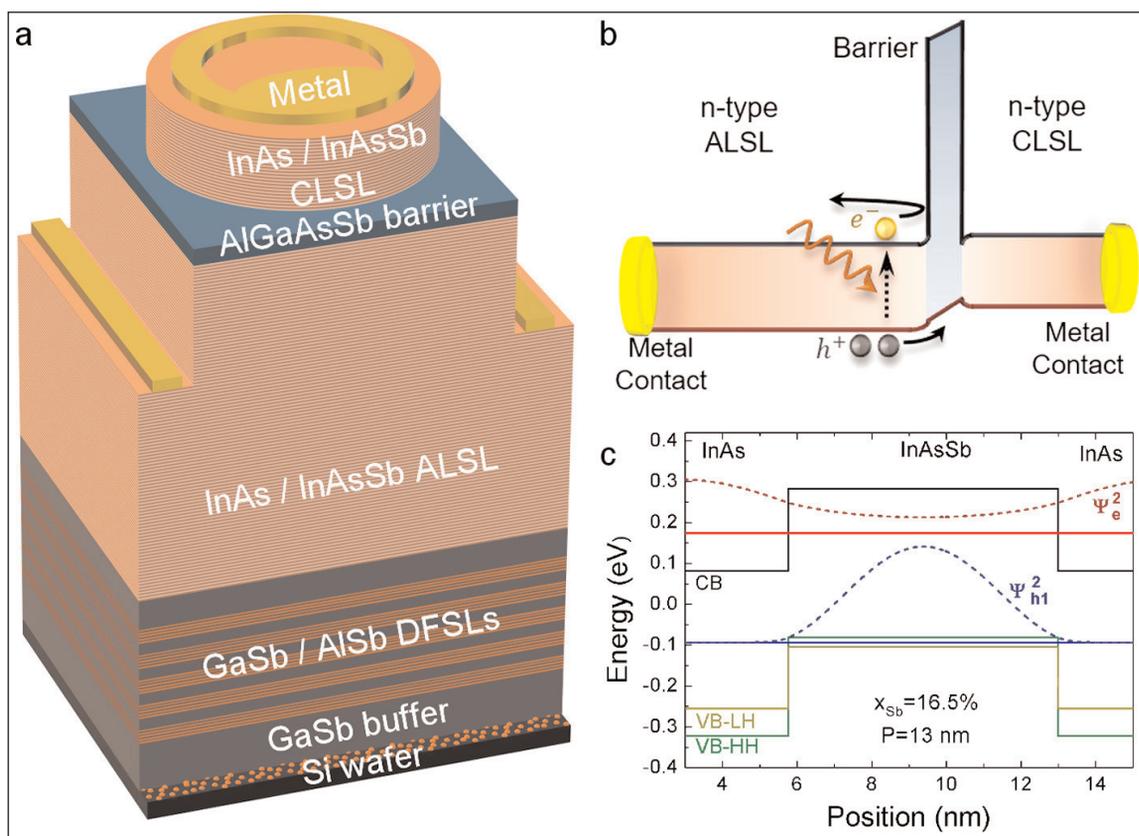
The researchers see opportunities for cost-effective silicon photonics and thermoelectrically cooled detection systems on silicon for the 3–5  $\mu\text{m}$ -wavelength MIR spectral range. Low-cost ultra-compact systems in the forms of large-area focal plane arrays and MIR integrated photonic circuits would find ready deployment in gas sensing, defense and medical diagnostics.

The usual materials used in the MIR range are mercury cadmium telluride (HgCdTe) alloys. The resulting devices are expensive to produce and need cryogenic cooling to reduce dark current.

The team explains the advantage of nBn photodetection: "These structures (often referred to as nBn) employ a wide-bandgap barrier layer positioned between narrow-bandgap

absorption and contact layers which blocks the flow of majority carriers (electrons), but not that of minority carriers (holes). A small applied bias falls almost completely across the barrier separating the photo-generated carriers. This almost entirely eliminates the electric field in the narrow-gap material, which greatly suppresses the junction-related Shockley–Read–Hall (SRH) dark current, resulting in significantly higher operating temperatures compared to conventional p-i-n photodiodes."

A number of epitaxial techniques were used to achieve low defect densities in the MIR-absorbing material. In addition, defects in InAsSb structures tend to have energy levels above the conduction band, rather



**Figure 1. (a) Schematic of InAs/InAsSb type-II SL nBn structure grown on top of GaSb/AlSb/Si buffer, using AlSb/GaSb dislocation filters. (b) Device bandgap structure with barrier blocking electron flow. (c) Calculated InAs/InAsSb SL bandstructure with first electron and hole energy levels and carrier density ( $\Psi^2$ ).**

than in the gap between the valence and conduction bands. This reduces the SRH dark current, since the mechanism flows through mid-gap levels.

Material growth began with a 17-monolayer AlSb nucleation grown by 490°C solid-source molecular beam epitaxy (SS-MBE) on 4°-miscut silicon (100) wafers (Figure 1). The nucleation included an optimized array of 90° interfacial misfit dislocations to encourage lateral rather than vertical propagation of defects. The spacing of the misfits was around 3.35nm.

The 2µm GaSb buffer was grown in two temperature steps at 490°C (1.5µm) and 515°C (0.5µm). The threading dislocations arising from the III-V/Si hetero-epitaxy were confined mainly to the first 700nm of the GaSb buffer. The buffer was also free of anti-phase domains.

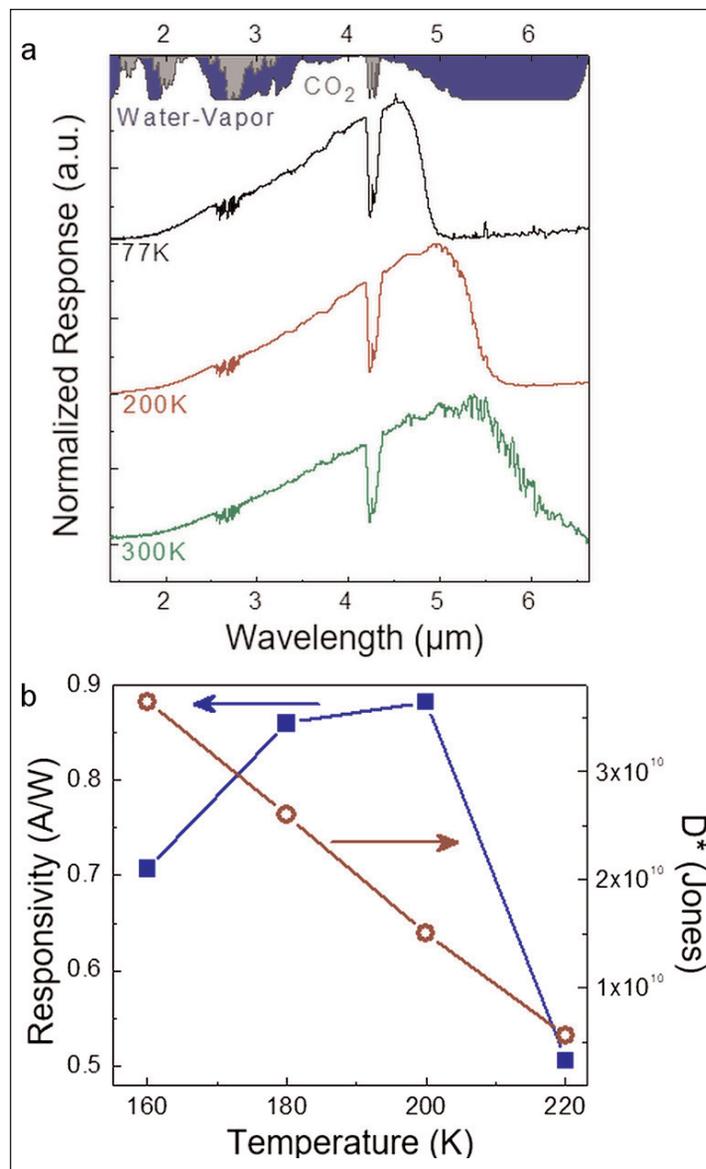
Five sets of strained AlSb/GaSb dislocation-filter superlattices (DFSLs) further improved the material quality of the device layers. Each superlattice set consisted of five repeats of 10nm/10nm GaSb/AlSb. The sets were separated by 300nm GaSb spacers. After filtering, the threading dislocation density was  $3 \times 10^7/\text{cm}^2$ .

The absorption-layer superlattice (ALSL) and contact-layer superlattice (CLSL) were 4µm and 400nm thick, respectively. They were separated by an  $\text{Al}_{0.9}\text{Ga}_{0.1}\text{As}_{0.1}\text{Sb}_{0.9}$  electron-blocking barrier with large conduction and small valence band offsets with the surrounding material. This enabled hole but not electron flow. The superlattice design consisted of 5.8nm/7.2nm InAs/InAs<sub>0.835</sub>Sb<sub>0.165</sub> pairs — 320-periods in the ALSL and 30-periods in the CLSL. The growth temperature was 430°C. Tellurium was used as n-type dopant.

Wet etching was used to create the mesas for the photodiode device. The metal contacts were titanium/gold. Under 100mV reverse bias, the dark current was  $8.65 \times 10^{-1} \text{A}/\text{cm}^2$  at room temperature, decreasing to  $1.2 \times 10^{-3} \text{A}/\text{cm}^2$  at 160K. While these values are lower than previously reported for Sb-based devices on silicon, HgCdTe devices typically have dark currents two orders of magnitude lower than the Lancaster/Warwick photodiode.

The spectral response under 100mV reverse bias had a 50% cut-off at 5.40µm at 200K, rising to 5.86µm at 300K/room temperature (Figure 2). The responsivity in the spectral range 3.7–4.9µm to an 823K blackbody source was 0.88A/W, representing a 25.6% external efficiency. At the slightly higher photodiode temperature of 220K, the response fell to 0.5A/W.

Specific detectivity ( $D^*$ ) calculations, which take into account thermal and shot noise limitations on performance, gave values of  $3.65 \times 10^{10}$  Jones at 160K and  $1.5 \times 10^{10}$  Jones at 200K. The researchers comment: "These results are higher than bulk InSb detectors



**Figure 2. (a) Normalized spectral response curves for detector at different temperatures (CO<sub>2</sub> absorption shown in gray, water vapor absorption in blue). (b) Total spectral responsivity and specific detectivity,  $D^*$ , values measured as function of temperature in 3.7–4.9µm spectral band.**

grown previously on silicon and that of InAs/GaSb SLs grown on GaAs. This can be attributed to the improved structural quality of the GaSb/Si buffer layers, and the reduced defect sensitivity provided by the InAs/InAsSb SL nBn design. However, they are about an order of magnitude lower than state-of-the-art InAs/InAsSb SL nBn photodetectors integrated on native GaSb substrate reported recently by Nasa JPL."

The team suggests that improved performance could come from back-side illumination or the use of anti-reflective coatings. As always, improved material quality with further reduced threading dislocation density would also help achieve lower dark currents. ■

<https://doi.org/10.1021/acsp Photonics.8b01550>

Author: Mike Cooke

# Graphene-enabled AlGaIn nanopyramid arrays on silicon

Researchers see potential applications for UV light-emitting diodes, photodetectors and lasers.

Researchers based in Norway and Germany have grown aluminium gallium nitride (AlGaIn) nanopyramid arrays using a graphene mask on silicon [A. Mazid Munshi et al, *Appl. Phys. Lett.*, vol113, p263102, 2018].

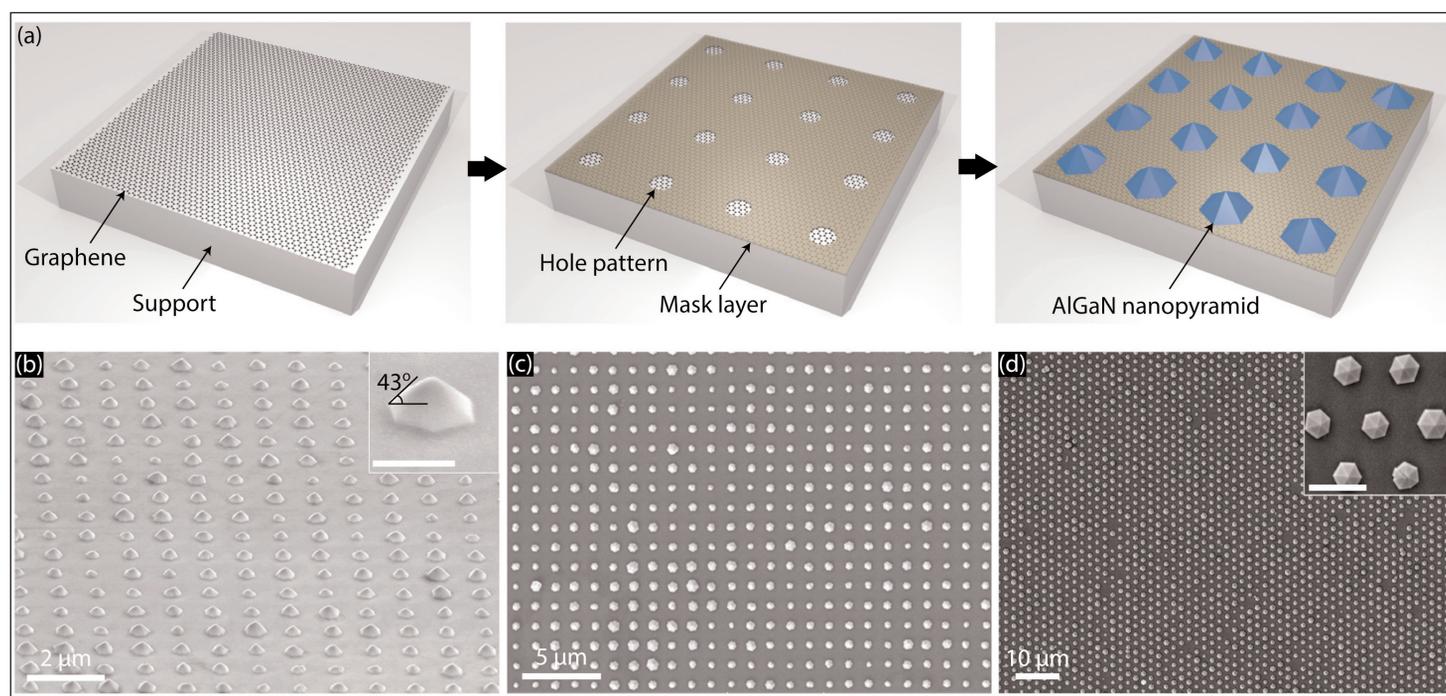
The team from CrayoNano AS in Norway, Germany's Max Planck Institute for the Science of Light and the Helmholtz Centre Berlin for Materials and Energy, and Norway's SINTEF Industry and the Norwegian University of Science and Technology (NTNU) see potential applications for ultraviolet (UV) light-emitting diodes, photodetectors, and lasers. They hope that such material could overcome the problem of planar III-nitride structures of defects arising from lattice and thermal expansion mismatching. Graphene enables quasi van der Waals epitaxy, avoiding problems arising from dangling chemical bonds.

Sub-400nm-wavelength UV light is used in curing, sensing, food processing and microbial disinfection of water and air. For sterilization applications the wavelength restriction is even more stringent — less than

~250nm deep UV is needed in order to be able to disrupt DNA structures, for example. These very short wavelengths need AlGaIn alloy material with high aluminium fractions. Until these problems are solved, systems will continue to rely on fragile, short-lifetime, toxic, bulky mercury lamps.

The single-layer graphene was grown by chemical vapor deposition (CVD) on copper foil and then transferred to 2-inch silicon (Si) substrates with native oxide layer. Electron-beam lithography was used to create a hole pattern in the graphene (Figure 1).

The AlGaIn nanopyramids were grown using metal-organic vapor phase epitaxy (MOVPE) with trimethylaluminum (TMAI), trimethylgallium (TMGa) and ammonia (NH<sub>3</sub>) precursors. Nitridation (optional) and nucleation, at 1200°C thermocouple reading, created islands from which nanopyramids were grown at 1150°C, with silane (SiH<sub>4</sub>) used for n-type doping. The researchers estimate that the growth surface temperature was about 100° less than the thermocouple reading.



**Figure 1. (a) Schematic of hole mask patterning and AlGaIn nanopyramid growth on graphene. Tilted- (b) and top-view (c) scanning electron microscope (SEM) images of AlGaIn nanopyramid arrays with 1µm-pitch square pattern showing good uniformity and very high nucleation yield. Inset (b): scale bar 400nm. (d) Top-view SEM image of AlGaIn nanopyramid array with 2µm pitch trigonal pattern. Inset (d): scale bar 2µm.**

The resulting nanopylramids had hexagonal bases. The side facets presented  $\{10\bar{1}2\}$  planes from the crystal structure, giving a  $\sim 43^\circ$  tilt angle to the substrate. "The formation of the  $\{10\bar{1}2\}$  side-facets is caused by the slow growth rate along the  $\langle 10\bar{1}2 \rangle$  directions due to the low  $\text{NH}_3$  flow used for the nanopylramid growth," the team explains. Some nanopylramids had poorly defined side facets – this was attributed to formation of multiple AlGaIn crystal seeds on the nucleation layer that subsequently merged.

The photoresponse from electron-beam excitation – cathodoluminescence (CL) – gave a peak at 366nm (Figure 2). There was also very strong defect-related luminescence around 550nm. The 366nm peak seems to come from pure GaN band-edge emission, despite the presence of  $\sim 2.8\%$  aluminium during growth. The researchers comment: "This indicates sub-optimal growth conditions with a reduced material quality, as evident also by the broad band-edge emission and strong defect luminescence, possibly caused by the use of low  $\text{NH}_3$  and high silane flows."

The low aluminium incorporation could be addressed in future by "modified growth techniques, e.g. pulsed-growth technique or using vertical flow MOVPE reactors".

The researchers added MOVPE AlGaIn/GaN/AlGaIn heterostructures to the nanopylramids, with the AlGaIn layers grown with 20% aluminium in the gas phase. The total overgrowth was around 300nm thick, according to transmission electron microscopy (TEM). The AlGaIn layers were grown for 15 minutes each, while the GaN deposition lasted 1 minute.

CL from the overgrown material showed a peak around 363nm, along with a number of peaks on the longer-wavelength shoulder, likely "whispering-gallery-like modes", according to the team. Defect-related

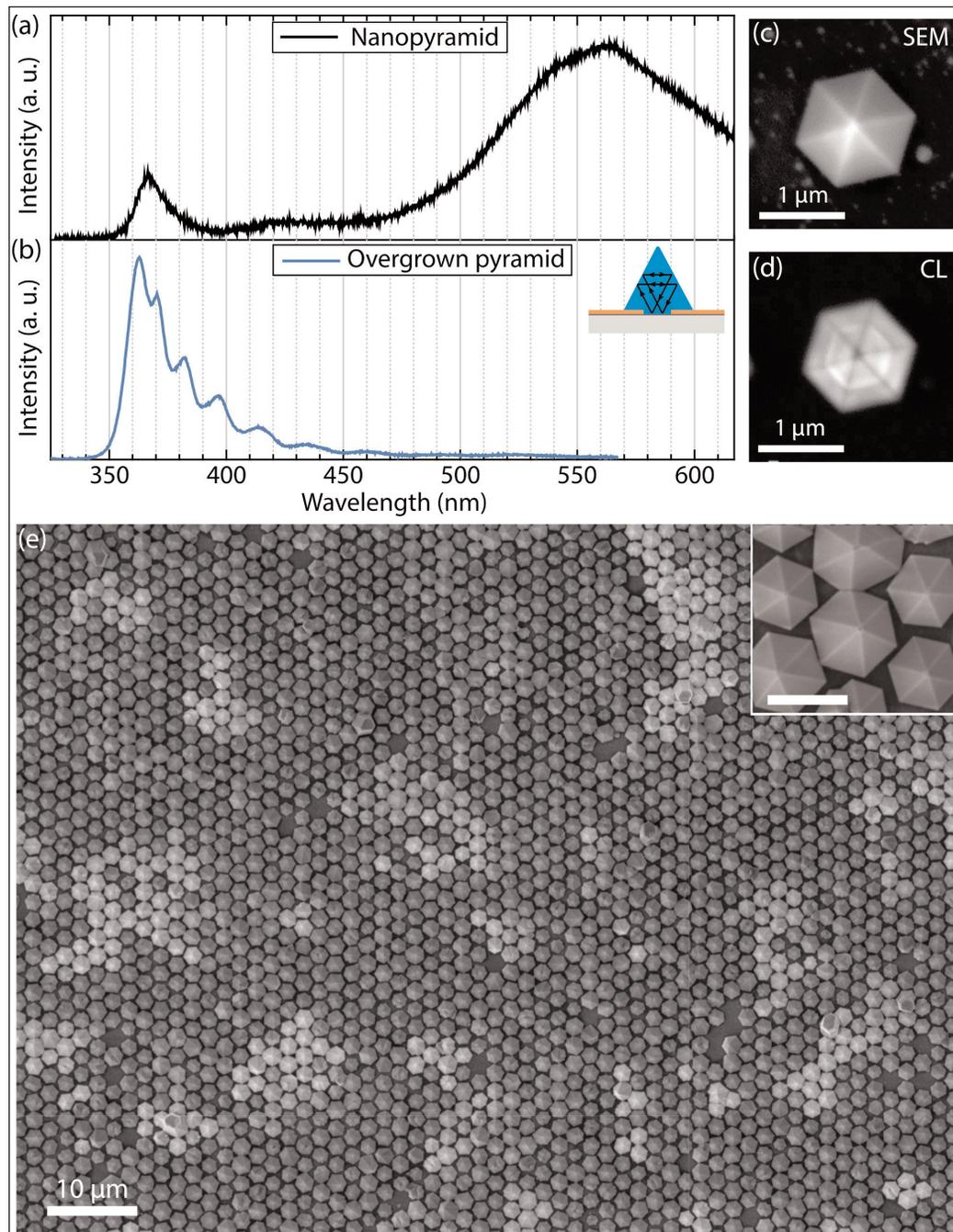
emissions were not seen in this case.

The researchers comment: "This superior optical quality of the overgrown pyramids may be caused by the use of high  $\text{NH}_3$  flow leading to the formation of a very regular hexagonal shape with smooth side-facets."

Cross-sectional TEM showed cavities at the bases of the nanopylramids, suggesting that the growth nucleates at the graphene edges of the holes. ■

<https://doi.org/10.1063/1.5052054>

Author: Mike Cooke



**Figure 2. (a) and (b) Room-temperature CL spectra obtained from single pyramid from sample in Figure 1 (b) and (c) and from overgrown pyramid. Inset (b): schematic of whispering gallery mode formation. (c) and (d) SEM image and panchromatic CL intensity mapping of same pyramid. (e) Top-view SEM overgrown pyramid arrays of sample in Figure 1 (d). Inset: magnified view of sample; scale bar 2µm.**

# Lateral graphene/hexagonal boron nitride heterostructures

**Chemical vapor deposition technique on copper foil points way to large-area uniform continuous films for device fabrication.**

**X**iamen University in China and University of Texas at Austin in the USA have developed a chemical vapor deposition (CVD) technique to grow two-dimensional heterostructures of hexagonal boron nitride (h-BN) and graphene (Gr) [Pingping Zhuang et al, Nanotechnology vol30, p03LT01, 2019]. Both h-BN and Gr adopt the hexagonal planar arrangement in monolayer two-dimensional sheets of atoms.

The researchers hope that the material could illuminate potential properties and effects such as electronic phase reconstruction across the one-dimensional h-BN/Gr interface, spin asymmetry induced magnetism, and topological ballistic transport.

Although the graphene domains were randomly distributed in terms of size, shape, and density, the potential for heterostructure-embedded electronic devices is enabled by the large-area uniform continuous films of CVD, compared with the laboratory-scale manipulation of micron-scale flakes seen in most device research reported so far. The researchers comment: "Further studies focusing on controllable growth based on this method are required to meet the device fabrication requirement."

The team used electro-polished carbon-containing copper (C-copper) foil as a substrate for the CVD of h-BN from aminoborane ( $\text{NH}_2\text{BH}_2$ ) and borazine ( $\text{B}_3\text{H}_6\text{N}_3$  in a benzene-like ring, hence the common

designation as 'inorganic benzene') precursors in hydrogen carrier gas (Figure 1).

The precursors were supplied by the decomposition of heated ammonia-borane ( $\text{BH}_3\text{NH}_3$ , AB) powders in a water bath. The C-copper foil was annealed before CVD at  $1035^\circ\text{C}$  to remove residual chemicals from the electro-polishing process (the reverse of electro-chemical deposition).

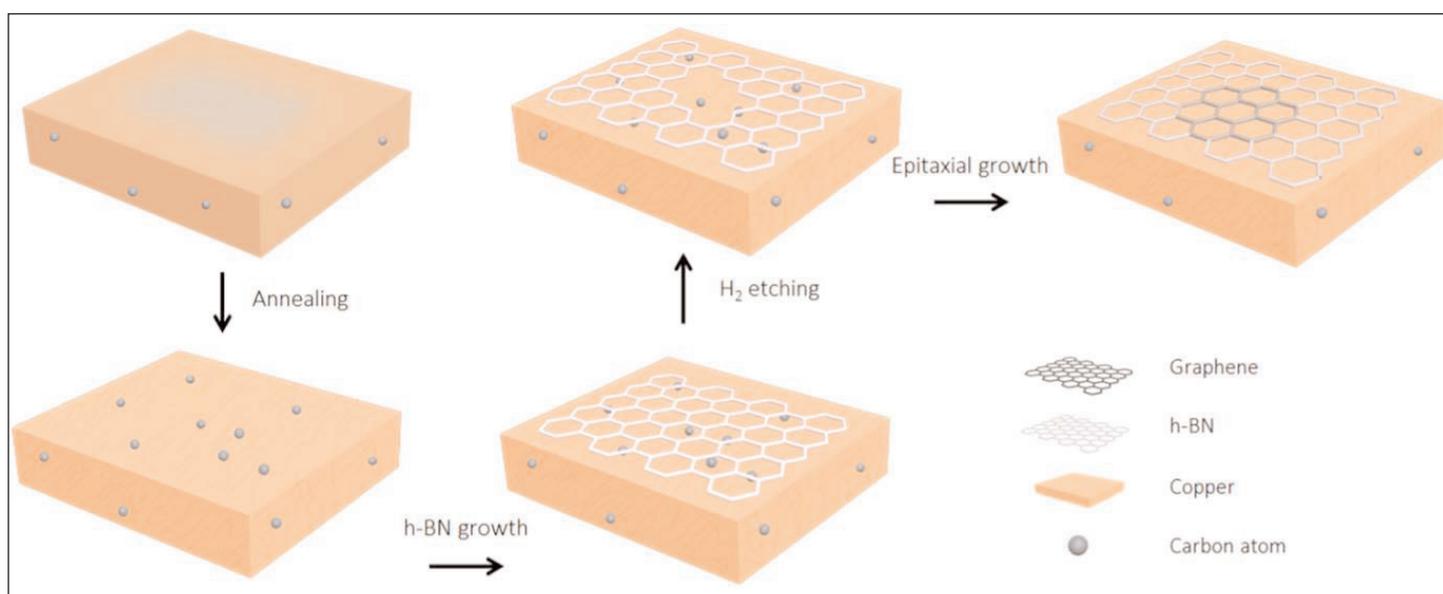
The hydrogen flow was maintained after the h-BN CVD, allowing partial etch of the film. Then, as the system was cooled, carbon atoms in the foil migrated to the edges of the h-BN structure, forming graphene domains in the gaps caused by hydrogen etching.

Under ultraviolet and visible radiation, the h-BN/Gr material transferred to quartz ( $\text{SiO}_2$ ) showed absorption peaks at 6.1eV and 4.2eV. The higher-energy photons were associated with the h-BN material, while the 4.2eV signal was attributed to the  $\pi$  plasmon peak in graphene. The researchers estimated a 'Tauc' optical bandgap for the h-BN/Gr combination of  $\sim 5.8\text{eV}$ .

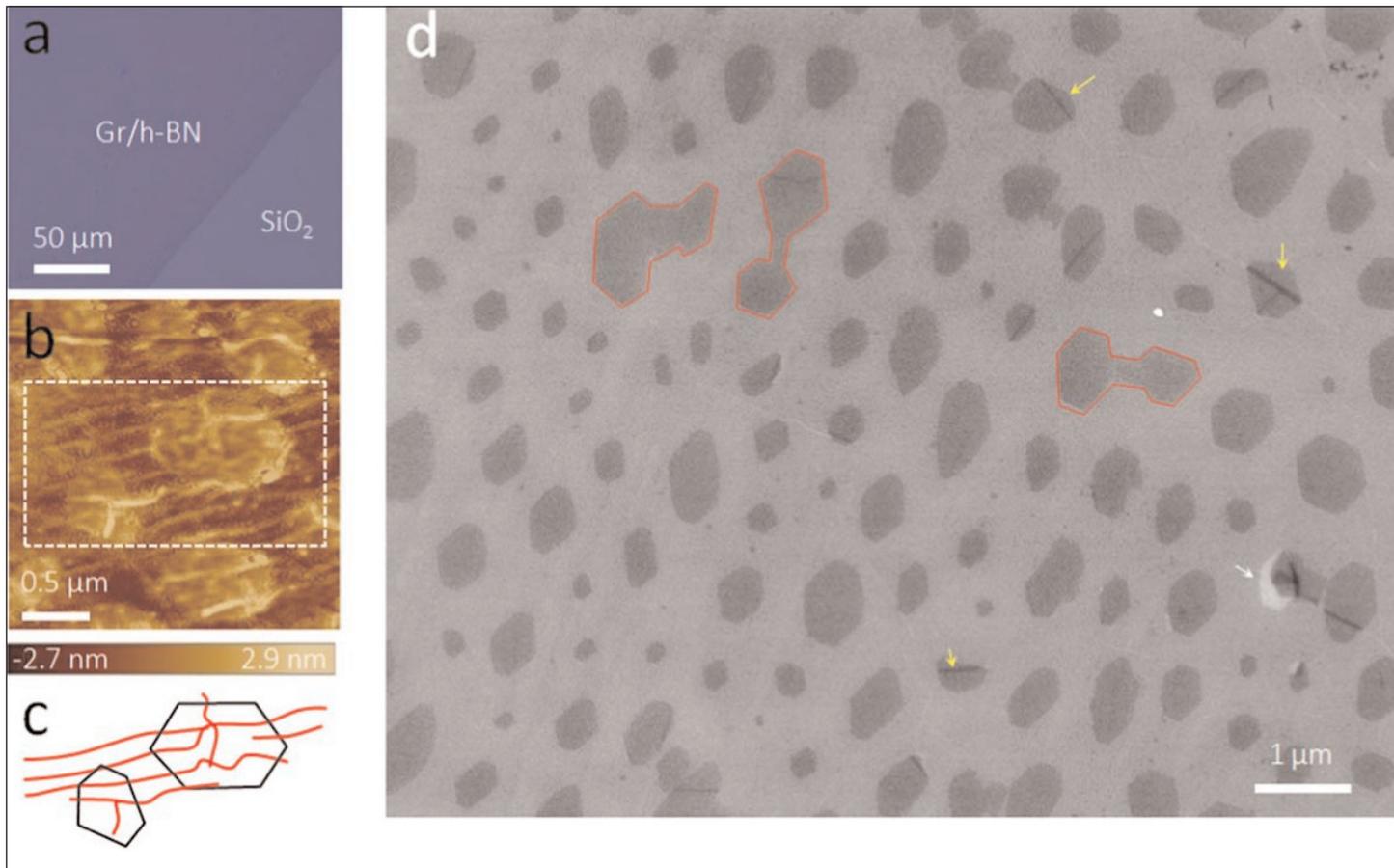
Other analyses were carried out on the material: Raman spectroscopy, atomic force microscopy (AFM), scanning electron microscopy (SEM), and x-ray photoelectron spectroscopy. ■

<https://doi.org/10.1088/1361-6528/aab75>

Author: Mike Cooke



**Figure 1. Schematic flow of lateral Gr/h-BN heterostructure growth on C-copper foils assisted by hydrogen etching.**



**Figure 2.** (a) Optical image of sample transferred to (PMMA). (b) AFM image of Gr/h-BN heterostructure. (c) Schematic outline of 1D interfaces (black) and wrinkles (red), which correspond to white-dashed rectangle marked area in (b). (d) SEM image of heterostructure transferred to silicon dioxide/silicon substrate. Aggregated graphene regions (red polygon), wrinkles (yellow arrow), and fracture (white arrow) are marked.

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# Selective-area emitter for gallium nitride bipolar transistors

An Ohmic base contact enables high current and power density as well as a current gain of 90, believed to be highest among reported devices on sapphire.

Researchers in China have improved the performance of gallium nitride (GaN) n-p-n heterojunction bipolar transistors (HBTs) on sapphire by growing the emitter layer selectively after the base and collector [Lian Zhang et al, IEEE Transactions On Electron Devices, vol66 (2019), no.3, p1197]. Selective-area growth (SAG) of the emitter layers avoids dry etch damage. Dry etch induces nitrogen vacancies and results in Schottky-type contacts for metal on p-GaN. The SAG enabled ohmic contact to the dry-etch-free p-type base layer.

The researchers at China's Institute of Semiconductors and Microsystem and Terahertz Research Center suggest that, with optimized contacts and device scaling to smaller dimensions, such an HBT could be promising for radio-frequency power amplifiers for next-generation wireless communications. HBTs tend to have better linearity and higher current and power density, enabling high-power and high-temperature operation, compared with high-electron-mobility transistors and variants.

The epitaxial layers were grown on sapphire through metal-organic chemical vapor deposition (MOCVD): 2 $\mu\text{m}$  GaN buffer, 1 $\mu\text{m}$  n-GaN subcollector, 500nm GaN collector, and 70nm p-GaN base.

The selective-area growth was prepared with a patterned layer of plasma-enhanced chemical vapor deposition (PECVD) silicon dioxide. The emitter layer was grown in a window in the silicon dioxide — 50nm n-AlGaN grown at 980°C and 200Torr pressure. The aluminium fraction was measured at around 7%. In fact, the AlGaN thickness was 150nm at the window edge and 120nm in the middle. Atomic force microscopy (AFM) gave a root-mean-square roughness of 0.371nm in a 5 $\mu\text{m}$ x5 $\mu\text{m}$  area.

While the fabricated HBTs had a variety of emitter sizes, the metal contacts were placed at fixed

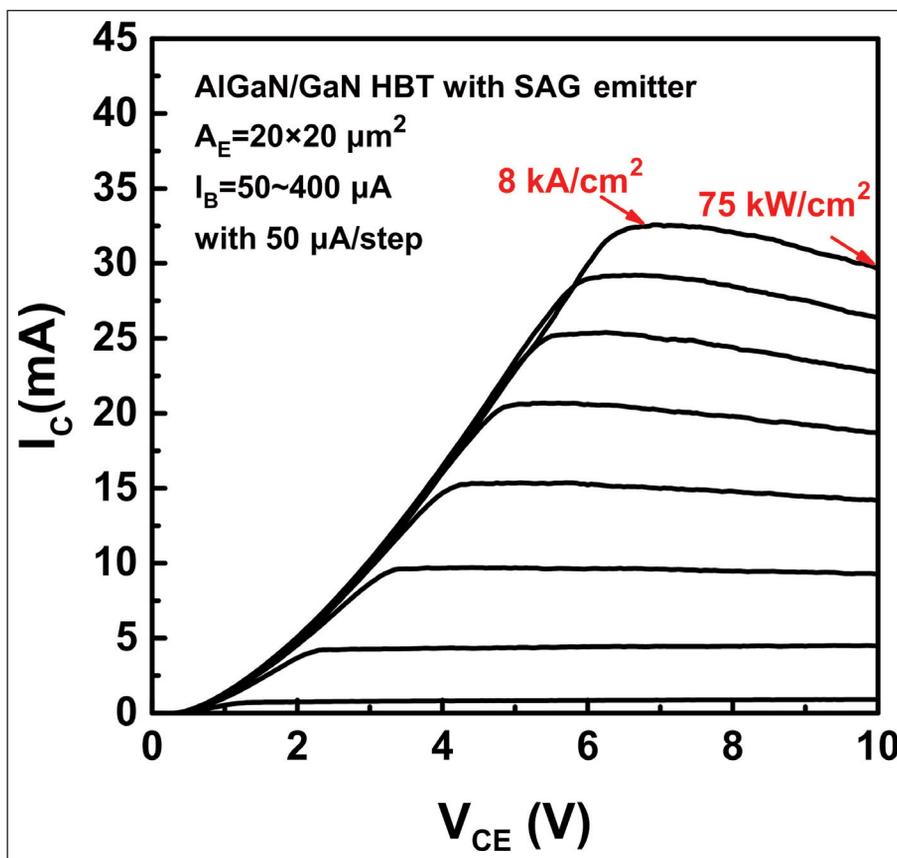


Figure 1. Common-emitter family curves.

distances from respective mesa edges — 2 $\mu\text{m}$  for the base and emitter metal to the base-emitter mesa, 2 $\mu\text{m}$  for the collector to the base-collector mesa, and 3 $\mu\text{m}$  for the base metal to the base-collector mesa.

An HBT with 20 $\mu\text{m}$ x20 $\mu\text{m}$  emitter area achieved 8kA/cm<sup>2</sup> collector current density ( $J_c$ ) and 75kW/cm<sup>2</sup> power density with collector-emitter voltages of 6.5V and 10V, respectively (Figure 1). "The high  $J_c$  and power density benefit from the realization of base ohmic contact that increases base conductivity and consequently enhances base current injection," the team comments.

The collector/base current gain was more than 80 when the base current exceeded 250 $\mu\text{A}$ . The maximum gain value of 90 for 0V base-collector bias was obtained at 7.7V base-emitter voltage (Figure 2).

The base current was 0.23mA. The 90 gain is believed to be the highest among reported devices on sapphire. The offset and knee voltages of less than 0.5V and 6.5V, respectively, represent the lowest reported for GaN-based HBTs of similar area, according to the researchers.

Devices with a larger emitter area had smaller gain values, likely due to defects at the base/emitter interface enabling tunneling.

The open-base breakdown voltage of the  $20\mu\text{m}\times 20\mu\text{m}$ -emitter HBT was 98V with  $1\mu\text{A}$  current compliance. The researchers believe that the voltage mainly dropped across the unintentionally doped GaN collector layer, giving an approximate breakdown field estimate of 2MV/cm, "comparable with reported direct-growth GaN-based HBTs".

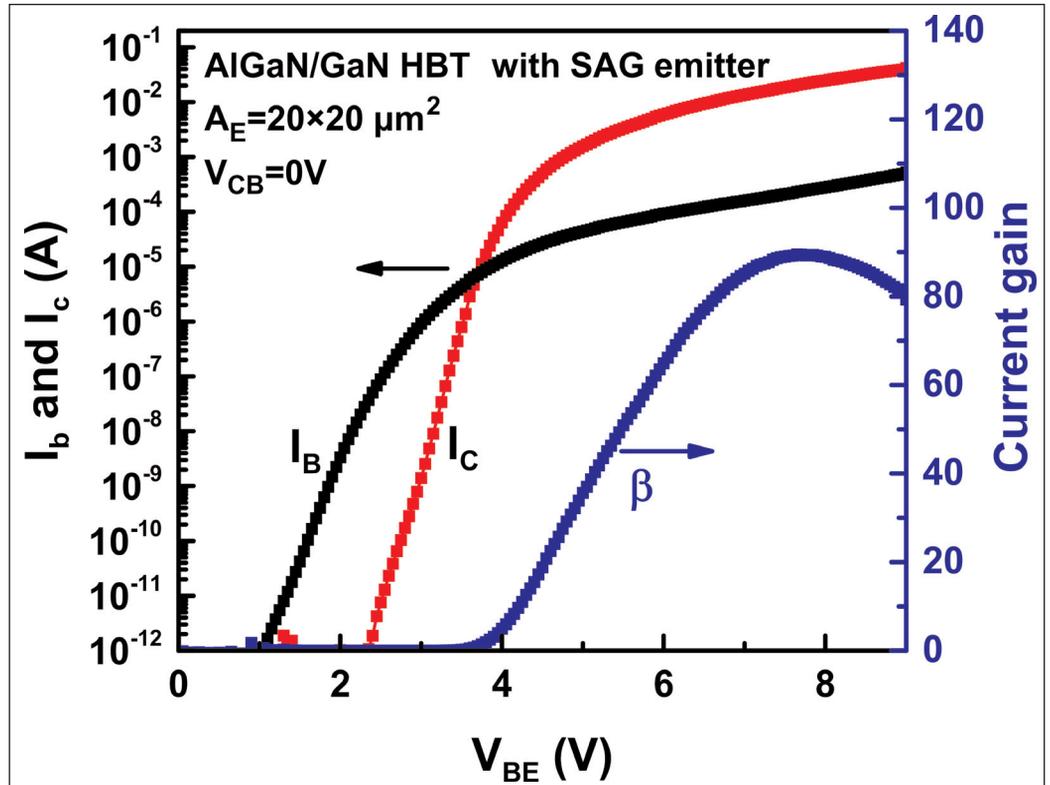


Figure 2. Gummel plot curves.

<http://english.semi.cas.cn>  
[www.mtrc.ac.cn/en](http://www.mtrc.ac.cn/en)

<https://doi.org/10.1109/TED.2018.2890207>

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# Diamond thermal management boosts output power of InAlGaN transistor

Researchers achieve more than 20W/mm  $\sim$ 3GHz S-band performance for indium-added barrier layer high-electron-mobility device.

Fujitsu Laboratories Ltd in Japan reports on diamond-based thermal management for  $\sim$ 3GHz indium aluminium gallium nitride (InAlGaN) high-electron-mobility transistors (HEMTs) on silicon carbide (SiC) [Toshihiro Ohki et al, IEEE Electron Device Letters, published online 5 December 2018]. Thermal management is a key step in achieving higher power density. Diamond is a material with a very high thermal conductivity.

The team comments: "An InAlGaN/GaN HEMT with a SiC/diamond-bonded heat spreader was developed and a high output power density of 22.3W/mm was achieved. This is the highest output power density among GaN HEMTs with an indium-added barrier layer

at the S- band."

The researchers see application in microwave high-power amplifiers, based on the high-voltage and high-frequency capability of electron flow in GaN channels. High power density is desired for strong signal transmission without distortion. For radar systems, high power extends the detection range.

The device material was grown on silicon carbide using metal-organic vapor phase epitaxy (MOVPE). The heterostructure featured an InGaN back barrier aimed at reducing drain current leakage. The top InAlGaN top barrier was grown on an AlGaN spacer in an effort to reduce interface roughness for improved electron mobility in the GaN channel.

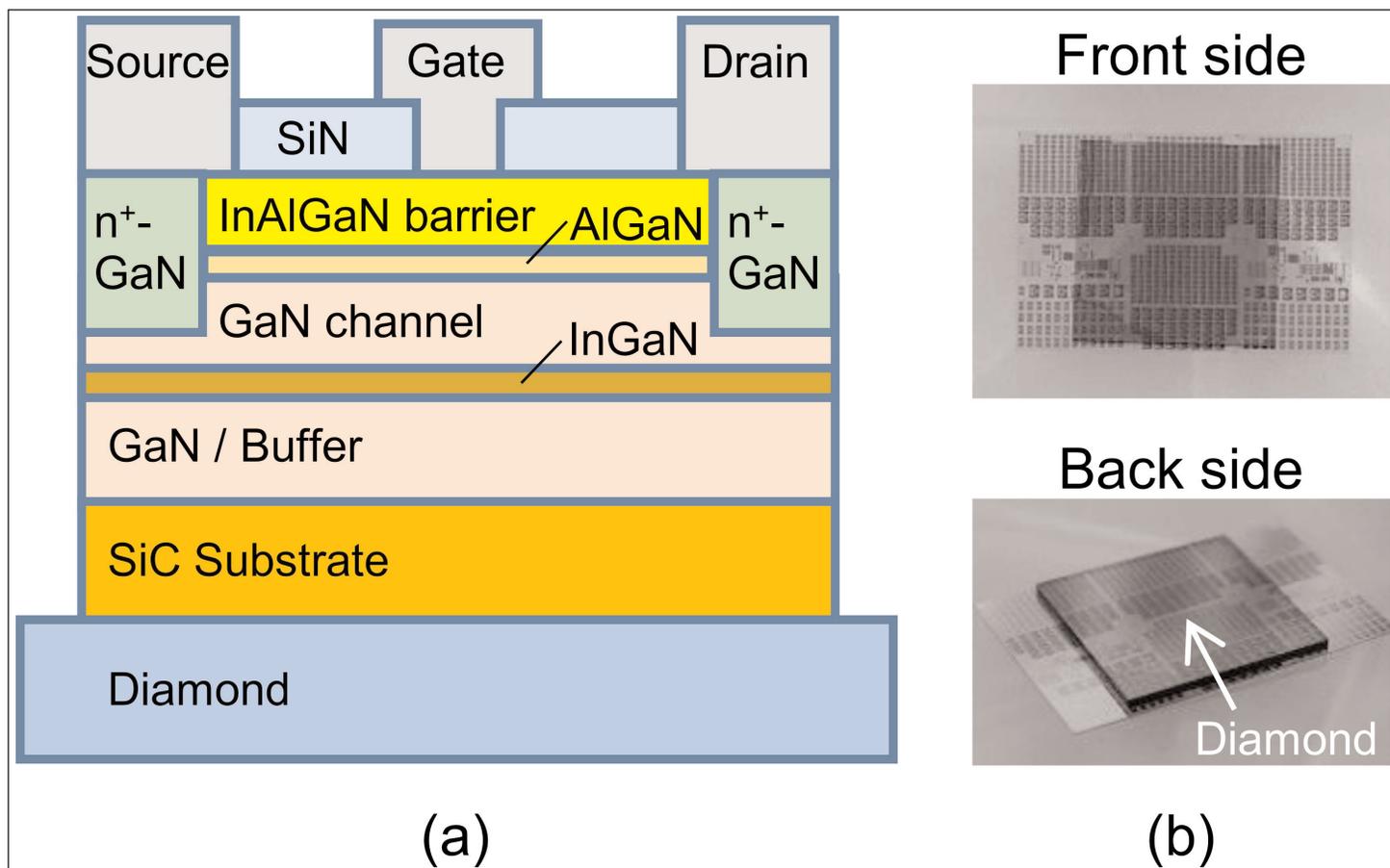


Figure 1. (a) Schematic cross-sectional view and (b) photographs of InAlGaN/GaN HEMT on SiC substrate bonded to diamond (9mmx9mm) heat spreader by surface-activated bonding.

Including indium in the top barrier material allows reduced sheet resistance in the channel without increasing tensile strain in the structure, as is inevitable with AlGaIn top barriers. The Fujitsu team reports that it has previously used InAlGaIn barriers to achieve higher output density than for AlGaIn/GaN HEMTs in the W-band range (75–110GHz).

W-band frequencies are allocated for satellite communications, millimeter-wave radar research, military radar targeting and tracking, and automotive cruise control radar. S-band (2–4GHz) applications also include radar, along with a number of local wireless communication devices (WiFi, Bluetooth, etc).

The source/drain contacts consisted of regrown  $n^+$ -GaIn and titanium/gold electrodes. The Schottky gate was nickel/gold. After thinning the SiC growth substrate to 50 $\mu$ m and smoothing with chemical mechanical polishing, the device was bonded to diamond.

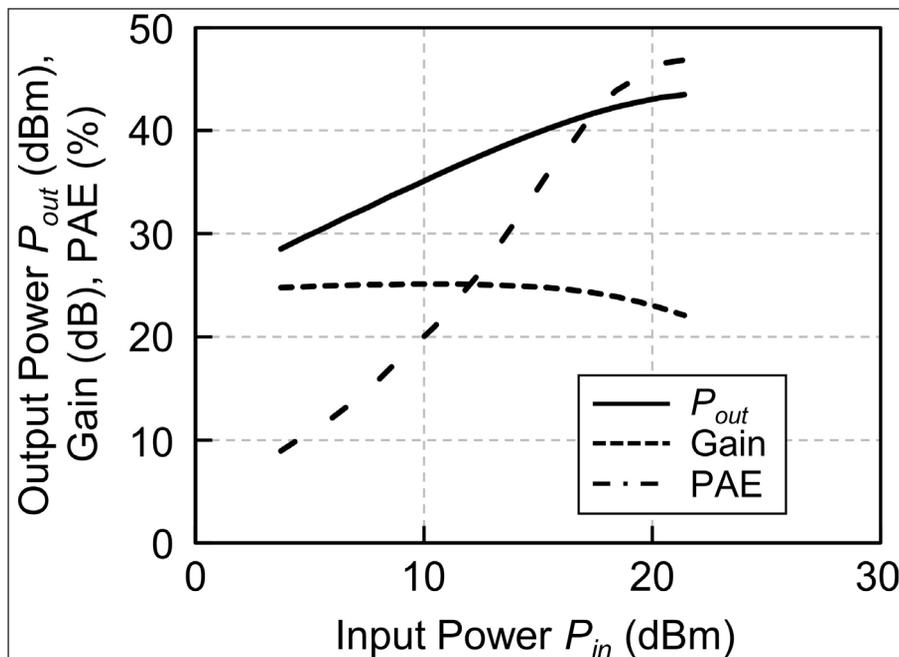
The interface between the SiC and diamond was made more thermally conductive by preparing the bond surfaces with argon beam treatment to remove contamination and activate the bond surfaces. The diamond surface also incorporated a thin metal layer that was applied before the argon exposure.

The researchers comment: "This process greatly improves the bonding strength between the SiC and diamond substrates because the formation of the low-density damaged layer on diamond surface is suppressed."

Optical microscope inspection of the bond could not find any voids. Mechanically peeling apart the device and diamond materials was difficult. These features suggest a strong bond with low thermal resistance.

A HEMT with 0.25 $\mu$ m $\times$ 50 $\mu$ m gate achieved a maximum drain current of 1058mA/mm and 488mS/mm peak transconductance. Three-terminal hard breakdown in pinch-off came at 257V. The researchers believe the high breakdown voltage was a result of the high growth temperature of the InAlGaIn barrier layer, giving higher crystal quality than in InAlIn barriers. The researchers report that the breakdown was comparable to what they have achieved with AlGaIn/GaN HEMTs fabricated in the same way.

**Improvements could come from "modulating the potential between the gate and drain electrode and decreasing the magnitude of the electric field at the gate edge"**



**Figure 2. Power characteristics of InAlGaIn/GaN HEMTs with diamond heat spreader evaluated by load-pull measurement under 1%-pulse condition at S-band.**

Thermal properties were assessed with an infrared camera. The device temperature reached 120°C with 12W input power on a diamond heat spreader. By contrast, without the diamond heat management it took only 4W to exceed 120°C. Thermal resistance around 100°C was 7.2°C/W for the HEMT on diamond, but this increased to 18.8°C/W without the heat spreader.

S-band microwave load-pull measurements around 3GHz demonstrated saturated output power of 19.8W/mm with a 1mm total gate width on diamond with 10% duty cycle of 10 $\mu$ s pulses. Without diamond, the power reached only 14.8W/mm. With a 1% duty cycle, the power on diamond increased to 22.3W/mm (Figure 2). The 1% duty cycle power-added efficiency (PAE) was calculated at 47% and the linear gain was 25.1dB.

The researchers point out that their work was limited by the maximum voltage of the measuring equipment and that higher drain biases (more than 100V) could give even better results. However, significant thermal degradation was seen with 10% duty cycle pulses for the HEMT on diamond — 10% duty cycles are common in radar and wireless communication devices.

Since the device does not presently use advanced field control structures, the team hopes that improvements could come from "modulating the potential between the gate and drain electrode and decreasing the magnitude of the electric field at the gate edge". Presumably, future performance targets would include the 40W/mm power density achieved so far by S-band AlGaIn/GaN HEMTs. ■

<https://doi.org/10.1109/LED.2018.2884918>

Author: Mike Cooke

# Octagonal cell topology for high-frequency SiC transistors

Researchers have reduced the gate capacitance and storage to produce improved figures of merit that reflect the trade-off with on-resistance.

**K**ijeong Han and BJ Baliga of North Carolina State University in the USA have developed 4H-polytype silicon carbide (4H-SiC) octagonal cell power metal-oxide-semiconductor field-effect transistors (MOSFETs) with reduced gate capacitance and charge, giving improved high-frequency figures of merit (HF-FOMs) over conventional linear-layout devices [IEEE Electron Device Letters, published online 21 December 2018].

The work represents the first “experimental demonstration of improved HF-FOMs for 4H-SiC power MOSFETs by using an octagonal-cell topology,” according to Han and Baliga. The devices were aimed at 1.2kV-rating applications.

The accumulation-mode channel (Accu) ‘OCTFET’ (Figure 1) used straight-edged structures, which can be defined more precisely in manufacturing than curves. However, simulations used to design the device used a circular approximation of the octagonal form to simplify the calculations.

The design sought to reduce capacitance and charge on the gate to enable faster switching speeds and lower power consumption. There was some trade-off

in increased specific on-resistance for the reduced capacitance/charge.

Accu OCFET device designs were sent to commercial foundry X-FAB in Texas, USA, for fabrication on 6-inch-diameter 4H-SiC silicon-face (0001) wafers. The junction FET region width ( $W_{\text{JFET}}$ ) varied between 0.9 $\mu\text{m}$  and 1.5 $\mu\text{m}$  (O\_J0.9-1.5). The channel-gate distance ( $a$ ) was also 1.1 $\mu\text{m}$ . The half-lengths of the bars connecting the four component JFETs ( $b$ ) was 1.1 $\mu\text{m}$ . A ‘compact’ version with smaller 0.55 $\mu\text{m}$  ‘ $b$ ’ value and  $W_{\text{JFET}}$  of 1.1 $\mu\text{m}$  was also produced (O\_J1.1\_C).

The n- and p-type regions were created using ion implantation of nitrogen and aluminium, respectively. The resultant doping was activated using 1650°C annealing with a carbon cap. Dry oxidation at 1175°C was used for the 50nm gate insulator. The insulator interface was also annealed in nitric oxide gas. The gate electrode was 500nm n-type polysilicon. Annealed nickel silicide was used for the ohmic source-drain contacts. The source and gate pads were aluminium. A solderable metal stack was applied to the back-side drain contact.

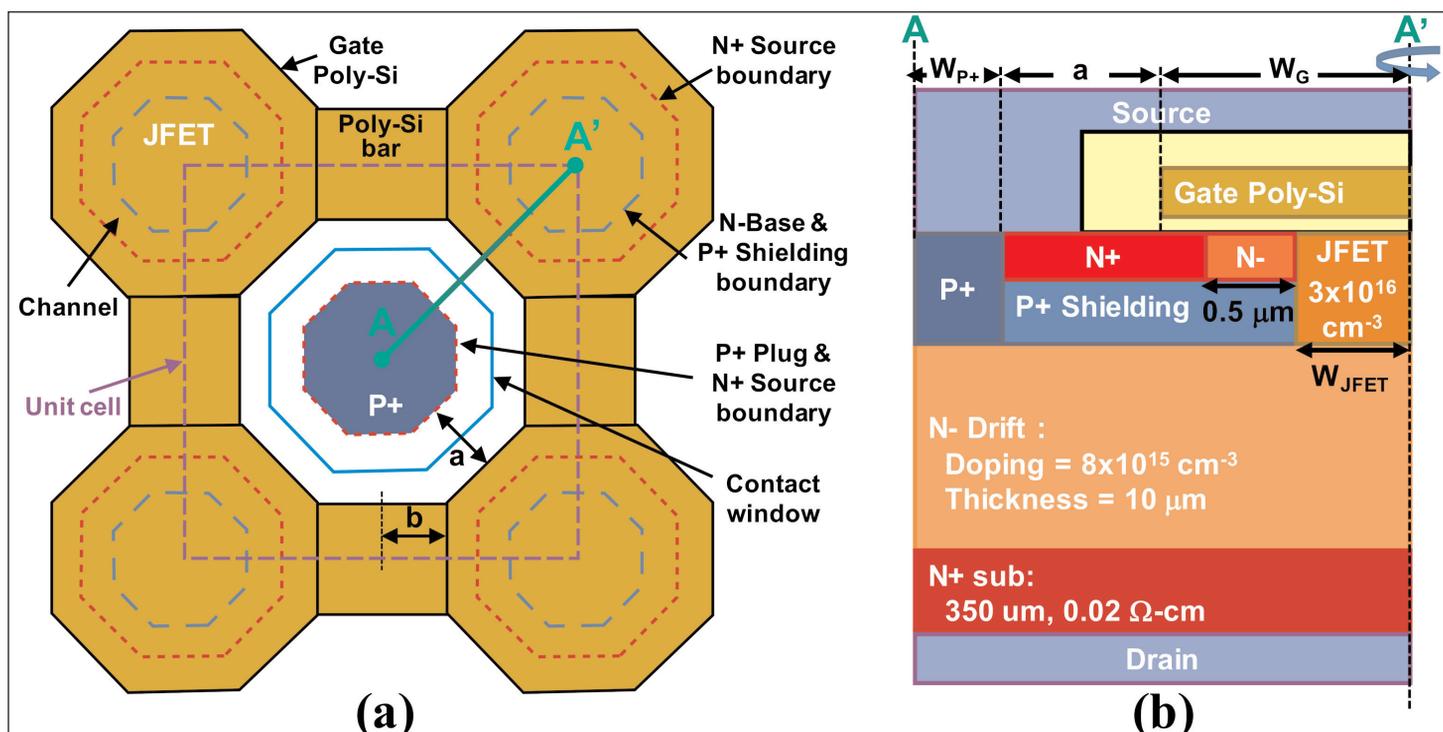


Figure 1. (a) OCTFET cell layout topology. (b) MOSFET cell cross section at A–A’.

**Table 1. Summary of experimental results for OCTFETs and conventional linear MOSFET.**

	<b>linear_J0.7</b>	<b>O_J0.9</b>	<b>O_J1.1</b>	<b>O_J1.3</b>	<b>O_J1.5</b>	<b>O_J1.1_C</b>
BV	1628V	1639V	1605V	1630V	1607V	1605V
$V_{th}$	1.96V	2.04V	2.02V	2.06V	2.12V	2.12V
$R_{on,sp}$	5.61m $\Omega$ -cm <sup>2</sup>	25.52m $\Omega$ -cm <sup>2</sup>	12.82m $\Omega$ -cm <sup>2</sup>	9.72m $\Omega$ -cm <sup>2</sup>	8.38m $\Omega$ -cm <sup>2</sup>	8.47m $\Omega$ -cm <sup>2</sup>
$C_{gd,sp}$	106pF/cm <sup>2</sup>	21pF/cm <sup>2</sup>	28pF/cm <sup>2</sup>	53pF/cm <sup>2</sup>	72pF/cm <sup>2</sup>	34pF/cm <sup>2</sup>
$Q_{gd,sp}$	311nC/cm <sup>2</sup>	67nC/cm <sup>2</sup>	113nC/cm <sup>2</sup>	160nC/cm <sup>2</sup>	233nC/cm <sup>2</sup>	144nC/cm <sup>2</sup>
RxC	595m $\Omega$ -pF	536m $\Omega$ -pF	359m $\Omega$ -pF	515m $\Omega$ -pF	603m $\Omega$ -pF	288m $\Omega$ -pF
RxQ	1745m $\Omega$ -nC	1710m $\Omega$ -nC	1449m $\Omega$ -nC	1555m $\Omega$ -nC	1953m $\Omega$ -nC	1220m $\Omega$ -nC

Devices with wider JFET regions had lower specific on-resistance ( $R_{on,sp}$ ) at gate potential of 20V and drain current 10A (Table 1). The values include the substrate resistance ( $\sim 0.7\text{m}\Omega\text{-cm}^2$ ). The compact device also performed well on this metric. A linear-layout comparison device with  $W_{JFET}$  of  $0.7\mu\text{m}$  had even lower specific on-resistance, due to a greater channel density. The results obtained were in line with the researchers' simulations.

The gate-drain capacitance ( $C_{gd,sp}$ ) and charge storage ( $Q_{gd,sp}$ ) were measured at drain biases of 1000V and 800V, respectively. In this case, the smaller- $W_{JFET}$  devices with reduced junction area performed best, while the linear comparison was even worse than the larger OCFETs.

The breakdown voltages (BVs) of all the devices were greater than 1600V, far exceeding the 1.2kV target rating. Threshold voltage ( $V_{th}$ ) with 0.1V drain bias for 1mA drain current were around 2V.

The HF-FOMs were based on the products of the specific on-resistance and capacitance/charge (RxC/RxQ), showing the lowest values for the compact device. The linear layout had 2.1x and 1.4x worse capacitance and charge HF-FOMs, respectively. Among the standard devices, the  $1.1\mu\text{m}$  OCFET was optimal, also beating the linear layout. ■

<https://doi.org/10.1109/LED.2018.2889221>

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# Gallium oxide prospects for high-voltage and high-power electronics

**Mike Cooke** reports on research plotting and exploring potential routes to commercial application.

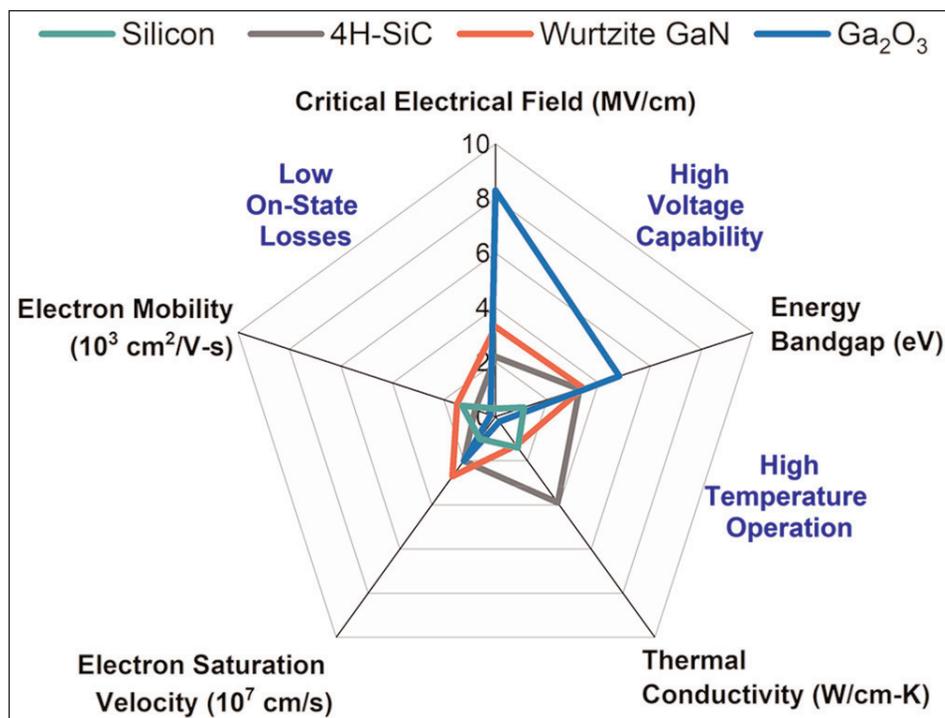
One always feels a flutter of excitement when one discovers that a material that one was barely aware of is being seriously considered for incorporation into the electronic constellation of useful semiconductors. Gallium oxide is one of the more recent contenders.

Gallium oxide has many properties that might be deployed in high-power electronic and radio-frequency amplifier applications: these include a wide bandgap of 4.5–4.9eV, implying a high critical electric field of up to 8MV/cm, and a reasonable electron mobility of the order 200cm<sup>2</sup>/V-s. Ga<sub>2</sub>O<sub>3</sub> breakdown voltages up to 3kV have been reported. Such devices could also be designed to operate under harsh and high-temperature conditions.

A further attraction of Ga<sub>2</sub>O<sub>3</sub> is the commercial availability of native substrates of the material at relatively low cost. This is based on the ability to use growth from molten gallium oxide to produce crystal material in the stable beta polytype. It is crystal growth from silicon melt that enables low cost, high-quality substrates for mainstream electronics.

University of Florida and the Naval Research Laboratory in the USA and Korea University have made a comprehensive review of the present and potential future status of gallium oxide (Ga<sub>2</sub>O<sub>3</sub>) electronics development [S. J. Pearton et al, *J. Appl. Phys.*, vol124, p220901, 2018]. The paper covers 19 pages, with about 4 pages of references.

Despite Ga<sub>2</sub>O<sub>3</sub>'s potential benefits (see Figure 1), the authors of the review see a number of hurdles to overcome. In the end, it is likely that Ga<sub>2</sub>O<sub>3</sub> electronic devices will provide complementary capabilities to existing silicon (Si), silicon carbide (SiC) and gallium nitride (GaN) technologies with bandgaps 1.1eV, ~3.3eV and ~3.4eV, respectively. The review team



**Figure 1. Pentagon diagram showing critical material properties important to power semiconductor devices. Larger pentagons are preferred. Data from G. Liu et al, *Appl. Phys. Rev.*, vol2, p021307, 2015; G. R. Chandra Mouli et al, *IEEE Trans. Power Electron.*, vol50, p97–103, 2018; B. J. Baliga, *Semicond. Sci. Technol.*, vol28, p074011 2013.**

sees Ga<sub>2</sub>O<sub>3</sub> as possibly contributing in the low-frequency high-voltage arena such as AC-to-DC conversion.

The team highlights “power conditioning systems, including pulsed power for avionics and electric ships, solid-state drivers for heavy electric motors, and advanced power management and control electronics” as potential applications (Figure 2).

Hurdles range from realizing usable, reliable components up to their insertion into sustainable market infrastructures. A big immediate drawback of Ga<sub>2</sub>O<sub>3</sub>, particularly in high-power-density applications, is a low thermal conductivity (10–30W/m-K versus SiC's 330W/m-K, GaN's 130W/m-K, and silicon's 130W/m-K). Thermal management strategies might include transfer of device layers to another, more heat-conducting

substrate, substrate thinning, heat sinks, top-side heat extraction, or active cooling with fans or liquid flow.

While  $\text{Ga}_2\text{O}_3$  can be doped for n-type (electron) mobility in a controllable manner, another obstacle is the lack of a complementary p-type doping mechanism. This is likely a fundamental problem, according to theoretical analyses.

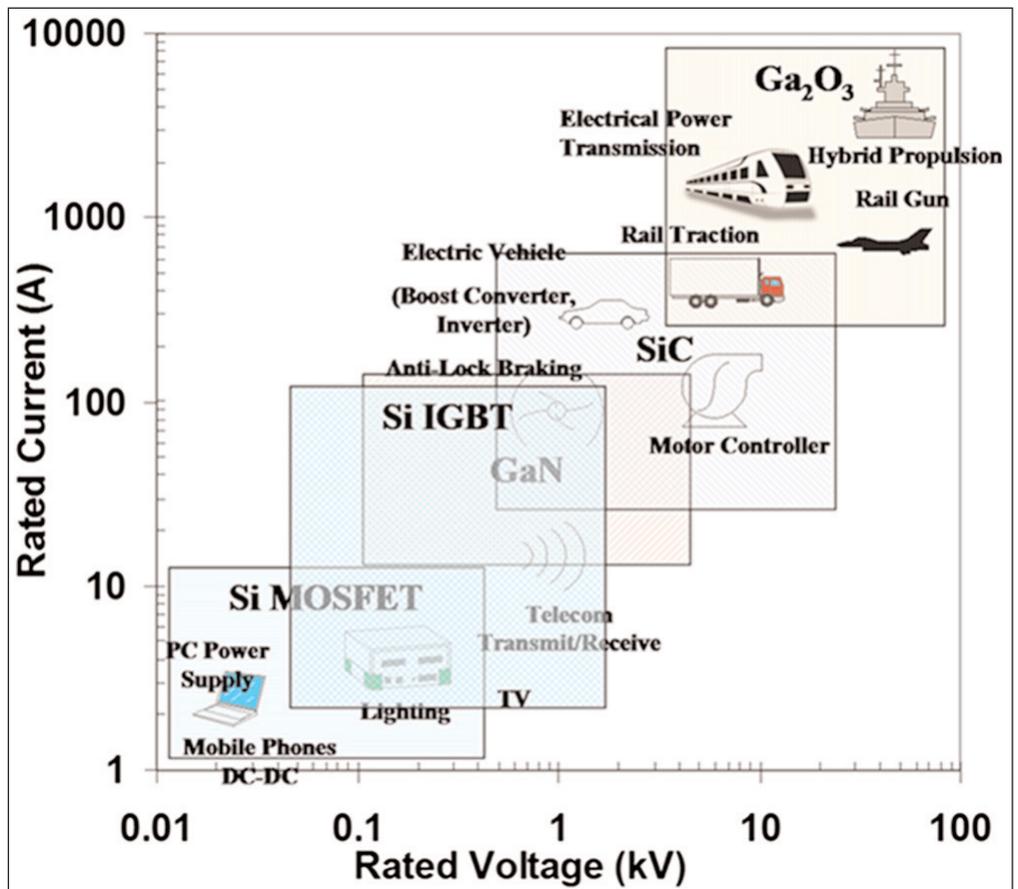
The reviewers report: "Self-trapping of holes in bulk  $\text{Ga}_2\text{O}_3$ , which decreases effective p-type conductivity owing to the resultant low mobility, is expected from the first-principles calculation of the  $\text{Ga}_2\text{O}_3$  band structure. Theory indicates that all the acceptor dopants result in deep acceptor levels, which were not able to produce p-type conductivity." Only at high temperature has there been any report of p-type conductivity, likely related to native Ga-vacancy defects.

The reviewers suggest that combining n- $\text{Ga}_2\text{O}_3$  with other semiconductor materials with p-type conductivity might be possible. Copper iodide, copper oxide and nickel oxide may be in contention for this role.

The team reports that the present market capacity is around \$15–22bn for discrete power devices. Making an analogy with the development of over 35 years from conception to commercialization of SiC devices, they ask who will bear the costs for  $\text{Ga}_2\text{O}_3$ 's progress to the same state?

The reviewers comment: "A key requirement is continued interest from military electronics development agencies. The history of the power electronics device field has shown that new technologies appear roughly every 10–12 years, with a cycle of performance evolution and optimization. The older technologies, however, survive long into the marketplace, for various reasons.  $\text{Ga}_2\text{O}_3$  may supplement SiC and GaN but is not expected to replace them."

The review adds: "Without an established revenue stream to support R&D over such a long time span, the clear driver has to be high-payoff military applications so that the necessary funding is there for long enough to truly develop this into a mature, manufacturable technology. It has never been the case with compound semiconductor power electronics that commercial applications have initially driven and sustained the development."



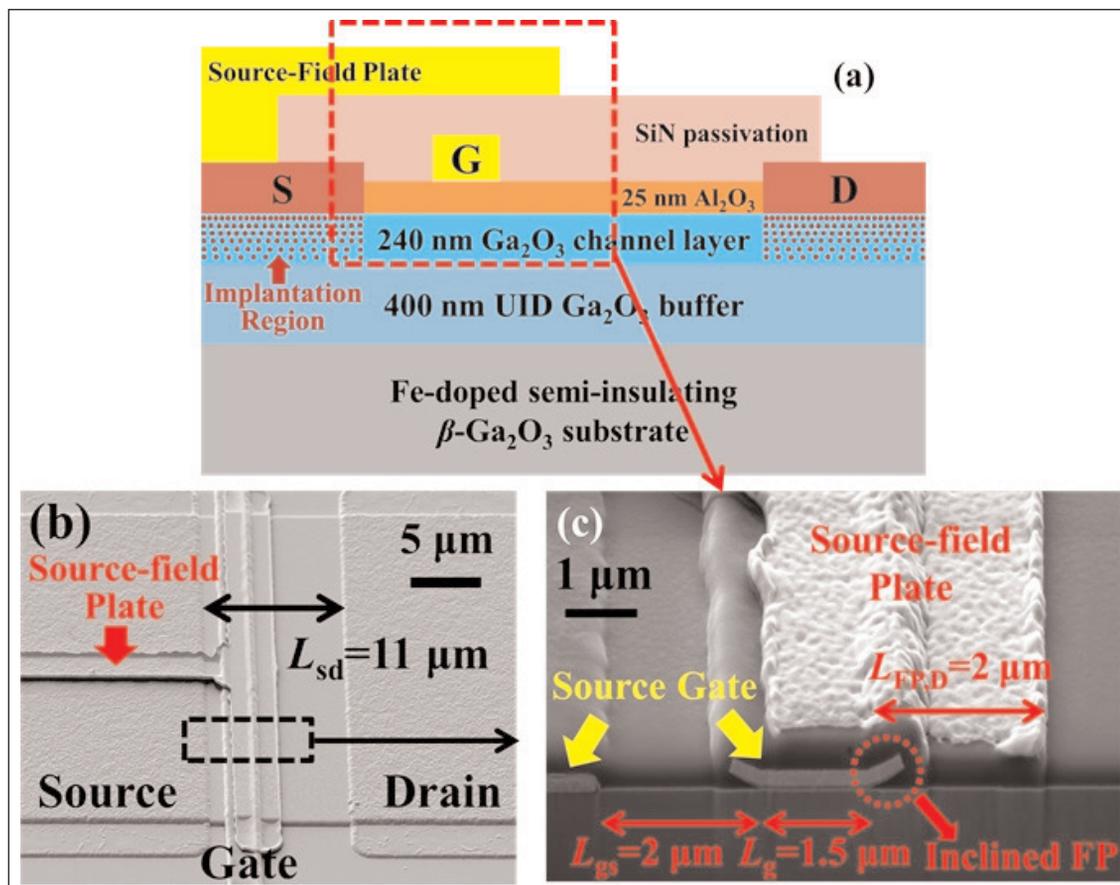
**Figure 2. Applications for Si, SiC, GaN and  $\text{Ga}_2\text{O}_3$  power electronics in terms of current and voltage requirements.**

Of course, these are views coming partly from the US Naval Research Laboratory. Further, the University of Florida team receives funding from the US Defense Threat Reduction Agency. However, it is undeniable that most of the early and continuing support of SiC and GaN power electronics development in the USA can be traced back to military research funding.

In Japan, where there has been some reluctance since World War II to be seen to engage directly in weapons markets, development of power technologies has been more focused on things like rail transport, electric motor vehicles, DC-AC conversion for renewable energy, power transmission (including high-voltage DC), control for electric motors in domestic appliances, and power supplies for consumer electronics. Who knows? If recent calls for a 'Green New Deal' in the USA begin to be taken seriously, maybe these drivers may gain more traction there too.

The review sees the need for improvement in  $\text{Ga}_2\text{O}_3$  development in seven areas: epitaxial growth, Ohmic contacts, thermally stable Schottky contacts, enhancement-mode (i.e. normally-off) transistor operation, reduction of dynamic on-resistance, process integration, and thermal management through passive and active cooling.

The reviewers suggest that a breakthrough for  $\text{Ga}_2\text{O}_3$  over the status quo is needed "in order to give it at



**Figure 3. (a) Schematic cross section of source-field-plated  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> MOSFET; and scanning electron microscope images of (b) surface and (c) cross section of device.**

least one application which will motivate R&D in the years to come.”

### Metal-oxide-semiconductor field-effect transistors

Some recent research may demonstrate the present stage of Ga<sub>2</sub>O<sub>3</sub> development. Hebei Semiconductor Research Institute and the Institute of Microelectronics in China have claimed record power figure of merit performance for  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> metal-oxide-semiconductor field-effect transistors (MOSFETs) [Yuanjie Lv et al, IEEE Electron Device Letters, vol40, p83, 2019].

The 50.4MW/cm<sup>2</sup> figure of merit ( $V_{br}^2/R_{on,sp}$ ) achieved represents a high breakdown voltage combined with a low specific on-resistance. High performance of one or the other factor usually entails a reduced characteristic on the other side of the trade-off.

The high figure of merit was achieved by using a source-connected field plate to reduce peak electric fields, increasing breakdown performance. Ion implants in the source and drain regions of the devices reduced contact resistance to 1.0 $\Omega$ -mm.

In theory with a critical electric breakdown field of order 8MV/cm it should be possible to reach a power figure of merit in the range 34,000MW/cm<sup>2</sup>, so there is clearly much scope for development and optimization work. Before the Hebei/Institute of Microelectronics

work the highest reported power figure of merit was 10MW/cm<sup>2</sup>.

The substrate for metal-organic chemical vapor deposition (MOCVD) was iron-doped semi-insulating (010)  $\beta$ -Ga<sub>2</sub>O<sub>3</sub>. The precursors were trimethyl-gallium and oxygen delivered at 8Torr pressure. The substrate temperature was 750°C. Silicon doping for the 240nm n-type channel layer (Figure 3) was provided by silane (SiH<sub>4</sub>) flow. Van der Pauw measurements gave an electron density of  $1.95 \times 10^{13}/\text{cm}^2$  with 90cm<sup>2</sup>/V-s mobility, and a sheet resistance  $\sim 3.6\text{k}\Omega/\text{square}$ .

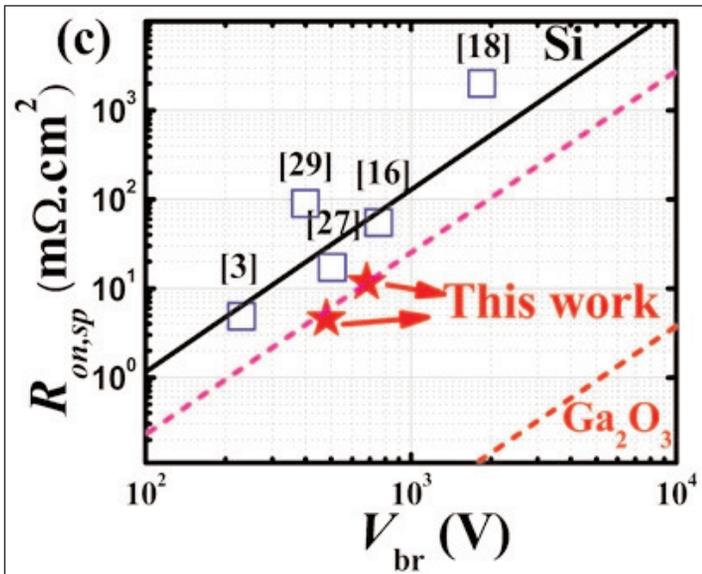
Inductively coupled plasma etch was used

to create a 350nm-high mesa for device fabrication. Source and drain regions were created with multiple implantations of silicon ions to a depth of  $\sim 210\text{nm}$ . Simulations predicted that the surface silicon concentration would be around  $10^{20}/\text{cm}^3$ . After annealing the doping implants, Ohmic source/drain (S/D) contacts were formed with deposition of titanium and gold. The gate (G) stack consisted of 25nm of 250°C atomic layer deposition (ALD) aluminium oxide (Al<sub>2</sub>O<sub>3</sub>) and nickel/gold metal electrode. The aluminium oxide was annealed before electrode deposition.

Surface passivation was provided by 400nm plasma-enhanced chemical vapor deposition (PECVD) silicon nitride (SiN). After reactive-ion etch to expose the source and drain metal, the nickel/gold source-connected field plate that extended 2 $\mu\text{m}$  toward the drain was formed.

The 1.5 $\mu\text{m}$ -long gate was 40 $\mu\text{m}$  wide. The gate-source distance was 2 $\mu\text{m}$ . Devices with gate-drain spacings of 7.5 $\mu\text{m}$  and 14.5 $\mu\text{m}$  were fabricated. The respective source-drain distances were 11 $\mu\text{m}$  and 18 $\mu\text{m}$ .

With the gate at 5V, the saturation drain current was 267mA/mm for the 11 $\mu\text{m}$  source-drain device and 222mA/mm for the 18 $\mu\text{m}$  version. Under the same gate potential, the low-drain-bias on-resistance was 41.6 $\Omega$ -mm in the 11 $\mu\text{m}$  source-drain transistor.



**Figure 4.** Three-terminal off-state breakdown characteristics of  $\beta$ - $\text{Ga}_2\text{O}_3$  MOSFET with and without source-field plate for (a)  $11\mu\text{m}$  and (b)  $18\mu\text{m}$  source-drain distance devices. (c) Plot of  $R_{\text{on,sp}}$  versus  $V_{\text{br}}$  for Hebei/Institute of Microelectronics devices ("this work") and other reported lateral  $\text{Ga}_2\text{O}_3$  MOSFETs.

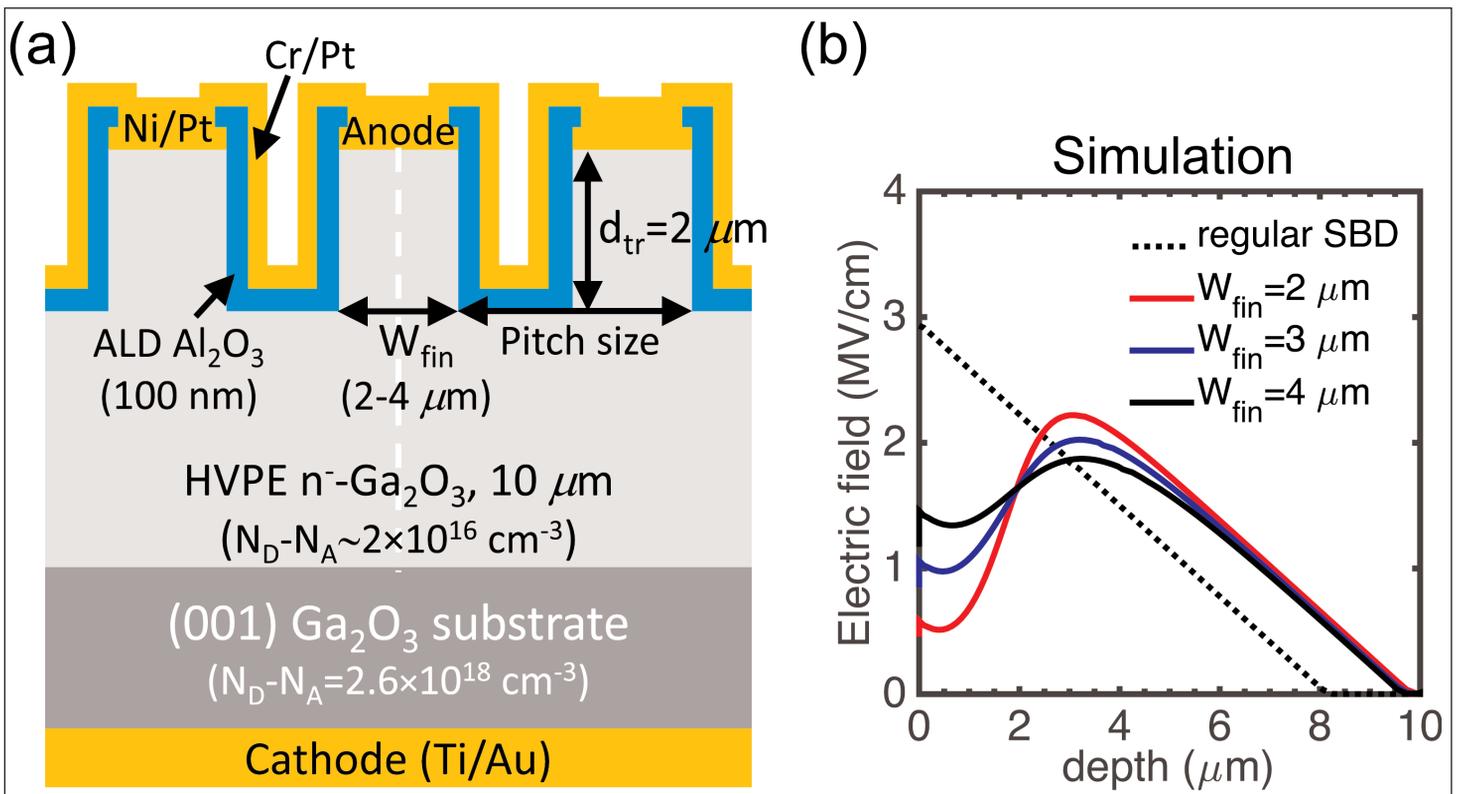
With 20V drain bias, the maximum transconductance for the  $11\mu\text{m}$  MOSFET was  $10.5\text{mS/mm}$ . The  $0.1\text{mA/mm}$  threshold gate voltage was at  $50.5\text{V}$ . Gate leakage was around  $7.1 \times 10^{-7}\text{A/mm}$ . The researchers see this value as being "comparatively

large", adding that the culprit may be  $\text{Al}_2\text{O}_3/\text{Ga}_2\text{O}_3$  interface traps. They suggest that these traps could be reduced with a better optimized surface-state treatment. Further evidence of interface traps was given by  $\sim 0.8\text{V}$  hysteresis in the response under forward and reverse sweeps of gate voltage. The on/off current ratio was of the order  $10^6$ .

Destructive breakdown performance in air was carried out with the gate at  $-55\text{V}$  (see Figure 4). Without source field plates, the breakdown voltages were  $310\text{V}$  and  $260\text{V}$  for the  $18\mu\text{m}$  and  $11\mu\text{m}$  MOSFETs, respectively. These values were greater than the  $218\text{V}$  value expected from a one-sided abrupt-junction model. The researchers suggest the better-than-theory result as being due to non-uniformity of channel doping and depletion from interface states. Adding source field plates increased the breakdown to  $480\text{V}$  in the  $11\mu\text{m}$  device and  $680\text{V}$  in the  $18\mu\text{m}$  MOSFET.

Multiplying the on-resistance by the source-drain distance to give  $R_{\text{on,sp}}$ , the researchers found values of  $4.58\text{m}\Omega\text{-cm}^2$  and  $11.7\text{m}\Omega\text{-cm}^2$  for the  $11\mu\text{m}$  and  $18\mu\text{m}$  devices, respectively. "Our fabricated devices in this work show much lower  $R_{\text{on,sp}}$  compared with other  $\beta$ - $\text{Ga}_2\text{O}_3$  MOSFETs and also with the theoretical performance of Si-based power devices," the team comments.

Although the saturation drain current is still lower than in reported nanomembrane  $\text{Ga}_2\text{O}_3$  devices, the researchers claim that their source-field-plated MOSFET shows a record maximum drain current and power



**Figure 5.** (a) Schematic cross section of  $\beta$ - $\text{Ga}_2\text{O}_3$  trench Schottky barrier diodes. (b) Simulated electric field profile at reverse bias of  $1200\text{V}$  along dashed vertical cut line at center of fin in (a).

figure of merit among devices fabricated on homo-epitaxial  $\beta$ -Ga<sub>2</sub>O<sub>3</sub>. The researchers suggest that increasing the channel layer thickness in conjunction with gate recessing could lead to lower on-resistance and associated improvement in the power figure of merit.

### Schottky barrier diodes

Cornell University in the USA and Novel Crystal Technology Inc in Japan claim the lowest leakage current yet reported for  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> Schottky barrier diodes (SBDs), another key device type for power applications [Wen-shen Li et al, Appl. Phys. Lett., vol113, p202101, 2018]. The low leakage current density of less than  $1\mu\text{A}/\text{cm}^2$  was combined with a relatively high breakdown voltage of 1232V. The devices used a trench structure to create fins with a metal-insulator-semiconductor (MIS) stack on the sidewalls to reduce surface field effects, suppressing leakage under reverse bias.

The researchers used halide vapor phase epitaxy (HVPE) to create the device layers of the SBD (Figure 5). The fin area ratio was  $\sim 60\%$  of the total fin+trench pitch. In simulations, a narrower fin was expected to result in lower electric fields near the top surface. The  $10\mu\text{m}$  drift layer had a uniform net doping of  $2 \times 10^{16}/\text{cm}^3$  that made a significant contribution to the improved performance.

Fabrication began with formation of the back cathode: first reactive ion etch (RIE) was performed to improve the ohmic nature of the contact, followed by evaporation and annealing of the titanium/gold (Ti/Au) contact metal.

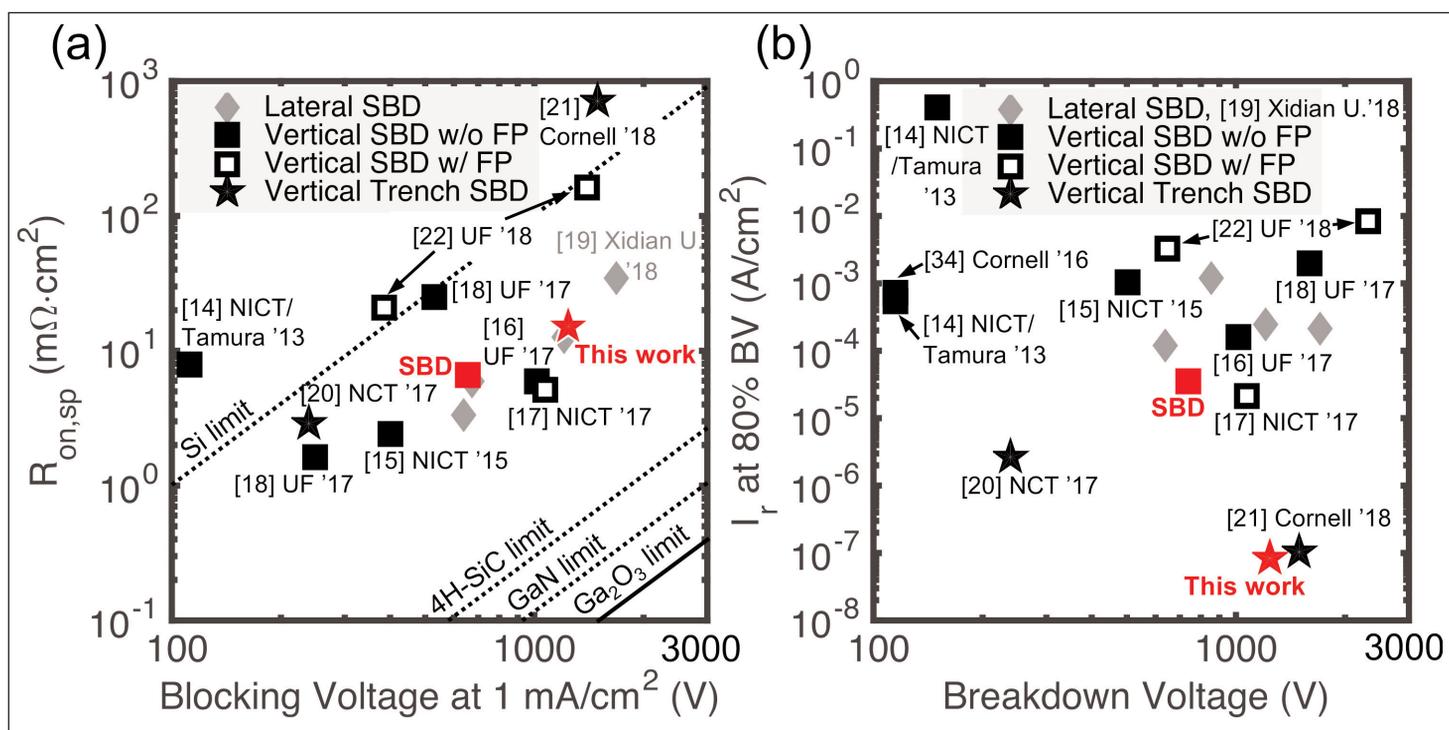
The front-side of the epitaxial wafer was patterned, using nickel/platinum (Ni/Pt) as both the hard mask for trench RIE etching and the Schottky contact of the final device. The trenches were etched to a depth of  $2\mu\text{m}$  with the fin channels oriented along the [010] direction. The fin sidewalls are described as being 'near vertical'.

The trenches were lined with atomic layer deposition Al<sub>2</sub>O<sub>3</sub>. Dry etch through the Al<sub>2</sub>O<sub>3</sub> at the tops of the fins exposed the nickel/platinum Schottky contacts. The device was completed with sputtering chromium/platinum (Cr/Pt) on the trench sidewalls.

The researchers also produced Ni/Pt Schottky diodes without the fin structuring, for comparison. The current densities were calculated based on device, not fin, area. The ideality factor of both devices was 1.08. The trench SBDs had a Schottky barrier height of 1.40eV, compared with 1.35eV for the regular device. The increased effective barrier height was attributed to the adjacent metal-oxide-semiconductor junction on the sidewalls of the trenches.

Pulsed measurements were used to avoid self-heating effects. The restricted area of the current flow through the fins resulted in reduced current density compared with the regular device. The specific differential on-resistance of the trench SBD was  $15\text{m}\Omega\text{-cm}^2$ , compared with  $6.6\text{m}\Omega\text{-cm}^2$  for the regular device.

The trench SBD also suffered from trapping effects in voltage scans not seen in the regular device. The researchers infer that "the trapping must be located at the trench MIS structure". The trapped charge increases



**Figure 6. Benchmark plots of state-of-the-art  $\beta$ -Ga<sub>2</sub>O<sub>3</sub> SBDs. (a) Differential  $R_{on,sp}$  excluding turn-on voltage, versus blocking voltage specified at reverse leakage current density of  $1\text{ mA}/\text{cm}^2$ . (b) Leakage current density at 80% of reported breakdown versus reported hard-breakdown voltage.**

the depletion in the fin, constricting current flow. The researchers estimate the extra depletion thickness to be of the order 170nm at zero bias, assuming a trapped electron sheet density of  $\sim 8 \times 10^{11}/\text{cm}^2$ .

The team suggests that the trapping could be reduced with a post-deposition anneal (PDA) of the  $\text{Al}_2\text{O}_3$  dielectric and with improved surface treatment on the  $\text{Ga}_2\text{O}_3$  surface after the dry etch.

The place where the trench SBD performed better was under reverse bias with breakdown at 1232V, compared with 734V for the regular device. The fins of the best trench SBD were 2 $\mu\text{m}$  wide. The leakage current before breakdown was less than  $1\mu\text{A}/\text{cm}^2$ , and when the reverse bias was below 1000V the leakage was less than  $0.1\mu\text{A}/\text{cm}^2$ , corresponding to power dissipation less than  $0.1\text{mW}/\text{cm}^2$ . Wider finned devices had higher leakage and lower breakdown voltages.

The team compared the performance of its devices with other reports (Figure 6). The specific differential on-resistance compared with the blocking voltage at  $1\text{mA}/\text{cm}^2$  current density showed 'notable' improvement over previously reported trench devices, while also

giving comparable performance to the best reported  $\beta\text{-Ga}_2\text{O}_3$  SBDs. The team comments: "In comparison with our previous results, the on-resistance is much reduced due to a more uniform doping profile with a moderate level ( $\sim 2 \times 10^{16}/\text{cm}^3$ ) and less carrier compensation."

Comparison was also made between the reverse leakage at 80% of breakdown and the breakdown voltage itself, showing lower leakage in the trench SBDs, compared with regular devices. The researchers claim the lowest leakage reported for the SBDs with 2 $\mu\text{m}$ -wide fins. The team's regular SBD showed similar performance to other reports. The lower leakage is therefore likely attributable to the trench structure itself.

The team expects progress toward the theoretical material limit for  $\text{Ga}_2\text{O}_3$  through reduced trapping in the MIS structure and better field management. ■

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*The author Mike Cooke is a freelance technology journalist who has worked in the semiconductor and advanced technology sectors since 1997.*

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Fax: +86 21 3360 7739

[metalorganicsAP@akzonobel.com](mailto:metalorganicsAP@akzonobel.com)

**Americas:**

AkzoNobel Functional Chemicals,  
Chicago,  
USA

Tel: +31 800 828 7929 (US only)

Tel: +1 312 544 7000

Fax: +1 312 544 7188

[metalorganicsNA@akzonobel.com](mailto:metalorganicsNA@akzonobel.com)

**Europe, Middle East and Africa:**

AkzoNobel Functional Chemicals,  
Amersfoort,  
The Netherlands

Tel: +31 33 467 6656

Fax: +31 33 467 6101

[metalorganicsEU@akzonobel.com](mailto:metalorganicsEU@akzonobel.com)

**Cambridge Chemical Company Ltd**

Unit 5 Chesterton Mills,  
French's Road,  
Cambridge CB4 3NP,  
UK

Tel: +44 (0)1223 352244

Fax: +44 (0)1223 352444

[www.camchem.co.uk](http://www.camchem.co.uk)

**Dow Electronic Materials**

60 Willow Street,  
North Andover, MA 01845,  
USA

Tel: +1 978 557 1700

Fax: +1 978 557 1701

[www.metalorganics.com](http://www.metalorganics.com)

**Matheson Tri-Gas**

6775 Central Avenue,  
Newark, CA 94560,  
USA

Tel: +1 510 793 2559

Fax: +1 510 790 6241

[www.mathesontrigas.com](http://www.mathesontrigas.com)

**Mining & Chemical Products Ltd**

(see section 1 for full contact details)

**Praxair Electronics**

542 Route 303, Orangeburg,  
NY 10962,  
USA  
Tel: +1 845 398 8242  
Fax: +1 845 398 8304  
[www.praxair.com/electronics](http://www.praxair.com/electronics)

**SAFC Hitech**

Power Road, Bromborough,  
Wirral, Merseyside CH62 3QF,  
UK  
Tel: +44 151 334 2774  
Fax: +44 151 334 6422  
[www.safchitech.com](http://www.safchitech.com)

**Materion Advanced Materials Group**

2978 Main Street,  
Buffalo, NY 14214,  
USA  
Tel: +1 716 837 1000  
Fax: +1 716 833 2926  
[www.williams-adv.com](http://www.williams-adv.com)

## 6 Deposition equipment

**AIXTRON SE**

Dornkaulstr. 2,  
52134 Herzogenrath,  
Germany  
Tel: +49 2407 9030 0  
Fax: +49 2407 9030 40  
[www.aixtron.com](http://www.aixtron.com)

**AIXTRON**

AIXTRON is a leading provider of deposition equipment to the semiconductor industry. The company's technology solutions are used by a diverse range of customers worldwide to build advanced components for electronic and optoelectronic applications (photonic) based on compound, silicon, or organic semiconductor materials and, more recently, carbon nanotubes (CNT), graphene and other nanomaterials.

**Evatec AG**

Hauptstrasse 1a,  
CH-9477 Trübbach, Switzerland  
Tel: +41 81 403 8000  
Fax: +41 81 403 8001  
[www.evatecnet.com](http://www.evatecnet.com)

**Ferrotec-Temescal**

4569-C Las  
Positas Rd,  
Livermore,  
CA 94551,  
USA  
Tel: +1 925 245 5817  
Fax: +1 925 449-4096  
[www.temescal.net](http://www.temescal.net)

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**Plasma-Therm LLC**

10050 16th Street North,  
St. Petersburg, FL 33716,  
USA  
Tel: +1 727 577 4999  
Fax: +1 727 577 7035  
[www.plasmatherm.com](http://www.plasmatherm.com)

**Riber**

31 rue Casimir Périer, BP 70083,  
95873 Bezons Cedex,  
France  
Tel: +33 (0) 1 39 96 65 00  
Fax: +33 (0) 1 39 47 45 62  
[www.riber.com](http://www.riber.com)

**SVT Associates Inc**

7620 Executive Drive,  
Eden Prairie, MN 55344,  
USA  
Tel: +1 952 934 2100  
Fax: +1 952 934 2737  
[www.svta.com](http://www.svta.com)

**Veeco Instruments Inc**

100 Sunnyside Blvd.,  
Woodbury, NY 11797,  
USA  
Tel: +1 516 677 0200  
Fax: +1 516 714 1231  
[www.veeco.com](http://www.veeco.com)



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## 7 Wafer processing materials

**Air Products and Chemicals Inc**

7201 Hamilton Blvd.,  
Allentown, PA 18195, USA  
Tel: +1 610 481 4911  
[www.airproducts.com/compound](http://www.airproducts.com/compound)

**MicroChem Corp**

1254 Chestnut St. Newton,  
MA 02464, USA  
Tel: +1 617 965 5511  
Fax: +1 617 965 5818  
[www.microchem.com](http://www.microchem.com)

**Praxair Electronics**

(see section 5 for full contact details)

## 8 Wafer processing equipment

**EV Group**

DI Erich Thallner Strasse 1,  
St. Florian/Inn, 4782,  
Austria  
Tel: +43 7712 5311 0  
Fax: +43 7712 5311 4600  
[www.EVGroup.com](http://www.EVGroup.com)

**Logitech Ltd**

Erskine Ferry Road,  
Old Kilpatrick,  
near Glasgow G60 5EU,  
Scotland, UK  
Tel: +44 (0) 1389 875 444  
Fax: +44 (0) 1389 879 042  
[www.logitech.uk.com](http://www.logitech.uk.com)

**Plasma-Therm LLC**

(see section 6 for full contact details)

**SAMCO International Inc**

532 Weddell Drive,  
Sunnyvale, CA,  
USA  
Tel: +1 408 734 0459  
Fax: +1 408 734 0961  
[www.samcointl.com](http://www.samcointl.com)

**SPTS Technology Ltd**

Ringland Way, Newport NP18 2TA,  
UK  
Tel: +44 (0)1633 414000  
Fax: +44 (0)1633 414141  
[www.spts.com](http://www.spts.com)

**SUSS MicroTec AG**

Schleißheimer Strasse 90,  
85748 Garching,  
Germany  
Tel: +49 89 32007 0  
Fax: +49 89 32007 162  
[www.suss.com](http://www.suss.com)

**Veeco Instruments Inc**

(see section 6 for full contact details)

## 9 Materials & metals

**Goodfellow Cambridge Ltd**

Ermine Business Park,  
Huntingdon,  
Cambridgeshire PE29 6WR,  
UK  
Tel: +44 (0) 1480 424800  
Fax: +44 (0) 1480 424900  
[www.goodfellow.com](http://www.goodfellow.com)



Goodfellow supplies small quantities of metals and materials for research, development, prototyping and specialised manufacturing operations.

## 10 Gas and liquid handling equipment

**Air Products and Chemicals Inc**

(see section 7 for full contact details)

**Cambridge Fluid Systems**

12 Trafalgar Way, Bar Hill,  
Cambridge CB3 8SQ,  
UK  
Tel: +44 (0)1954 786800  
Fax: +44 (0)1954 786818  
[www.cambridge-fluid.com](http://www.cambridge-fluid.com)

**CS CLEAN SOLUTIONS AG**

Fraunhoferstrasse 4,  
Ismaning, 85737,  
Germany  
Tel: +49 89 96 24000  
Fax: +49 89 96 2400122  
[www.csclean.com](http://www.csclean.com)

**SAES Pure Gas Inc**

4175 Santa Fe Road,  
San Luis Obispo,  
CA 93401,  
USA  
Tel: +1 805 541 9299  
Fax: +1 805 541 9399  
[www.saesgetters.com](http://www.saesgetters.com)

## 11 Process monitoring and control

**Conax Technologies**

2300 Walden Avenue,  
Buffalo, NY 14225,  
USA  
Tel: +1 800 223 2389  
Tel: +1 716 684 4500  
E-mail: [conax@conaxtechnologies.com](mailto:conax@conaxtechnologies.com)



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**k-Space Associates Inc**

2182 Bishop Circle  
East, Dexter, MI 48130,  
USA  
Tel: +1 734 426 7977  
Fax: +1 734 426 7955  
[www.k-space.com](http://www.k-space.com)

**KLA-Tencor**

One Technology Dr,  
1-2221I, Milpitas,  
CA 95035,  
USA  
Tel: +1 408 875 3000  
Fax: +1 408 875 4144  
[www.kla-tencor.com](http://www.kla-tencor.com)

**LayTec AG**

Seesener Str.   
10-13,  
10709 Berlin,  
Germany  
Tel: +49 30 89 00 55 0  
Fax: +49 30 89 00 180  
[www.laytec.de](http://www.laytec.de)

LayTec develops and manufactures optical in-situ and in-line metrology systems for thin-film processes with particular focus on compound semiconductor and photovoltaic applications. Its know-how is based on optical techniques: reflectometry, emissivity corrected pyrometry, curvature measurements and reflectance anisotropy spectroscopy.

**WEP (Ingenieurbüro Wolff für Elektronik- und Programmentwicklungen)**

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D-78120 Furtwangen im  
Schwarzwald,  
Germany  
Tel: +49 7723 9197 0  
Fax: +49 7723 9197 22  
[www.wepcontrol.com](http://www.wepcontrol.com)

## 12 Inspection equipment

**Bruker AXS GmbH**

Oestliche Rheinbrueckenstrasse 49,  
Karlsruhe, 76187,  
Germany  
Tel: +49 (0)721 595 2888  
Fax: +49 (0)721 595 4587  
[www.bruker-axs.de](http://www.bruker-axs.de)

## 13 Characterization equipment

**J.A. Woollam Co. Inc.**

645 M Street Suite 102,  
Lincoln, NE 68508, USA  
Tel: +1 402 477 7501  
Fax: +1 402 477 8214  
[www.jawoollam.com](http://www.jawoollam.com)

**Lake Shore Cryotronics Inc**

575 McCorkle Boulevard,  
Westerville, OH 43082, USA  
Tel: +1 614 891 2244  
Fax: +1 614 818 1600  
[www.lakeshore.com](http://www.lakeshore.com)

## 14 Chip test equipment

### Keithley Instruments Inc

28775 Aurora Road,  
Cleveland, OH 44139, USA  
Tel: +1 440.248.0400  
Fax: +1 440.248.6168  
[www.keithley.com](http://www.keithley.com)

## 15 Assembly/packaging materials

### ePAK International Inc

4926 Spicewood Springs Road,  
Austin, TX 78759,  
USA  
Tel: +1 512 231 8083  
Fax: +1 512 231 8183  
[www.epak.com](http://www.epak.com)

### Gel-Pak

31398 Huntwood Avenue,  
Hayward, CA 94544, USA  
Tel: +1 510 576 2220  
Fax: +1 510 576 2282  
[www.gelpak.com](http://www.gelpak.com)

### Wafer World Inc

(see section 3 for full contact details)

### Materion Advanced Materials Group

2978 Main Street,  
Buffalo, NY 14214,  
USA  
Tel: +1 716 837 1000  
Fax: +1 716 833 2926  
[www.williams-adv.com](http://www.williams-adv.com)

## 16 Assembly/packaging equipment

### Ismeca Europe Semiconductor SA

Helvetie 283, La Chaux-de-Fonds,  
2301, Switzerland  
Tel: +41 329257111  
Fax: +41 329257115  
[www.ismeca.com](http://www.ismeca.com)

### Kulicke & Soffa Industries

1005 Virginia Drive,  
Fort Washington, PA 19034,  
USA  
Tel: +1 215 784 6000  
Fax: +1 215 784 6001  
[www.kns.com](http://www.kns.com)

### Palomar Technologies Inc

2728 Loker Avenue West,  
Carlsbad, CA 92010,  
USA  
Tel: +1 760 931 3600  
Fax: +1 760 931 5191  
[www.PalomarTechnologies.com](http://www.PalomarTechnologies.com)

### TECDIA Inc

2700 Augustine Drive, Suite 110,  
Santa Clara, CA 95054,  
USA  
Tel: +1 408 748 0100  
Fax: +1 408 748 0111  
[www.tecdia.com](http://www.tecdia.com)

## 17 Assembly/packaging foundry

### Quik-Pak

10987 Via Frontera,  
San Diego, CA 92127,  
USA  
Tel: +1 858 674 4676  
Fax: +1 8586 74 4681  
[www.quikicpak.com](http://www.quikicpak.com)

## 18 Chip foundry

### Compound Semiconductor Technologies Ltd

Block 7, Kelvin Campus,  
West of Scotland, Glasgow,  
Scotland G20 0TH,  
UK  
Tel: +44 141 579 3000  
Fax: +44 141 579 3040  
[www.compoundsemi.co.uk](http://www.compoundsemi.co.uk)

### United Monolithic Semiconductors

Route departementale 128,  
BP46, Orsay, 91401,  
France  
Tel: +33 1 69 33 04 72  
Fax: +33 169 33 02 92  
[www.ums-gaas.com](http://www.ums-gaas.com)

## 19 Facility equipment

### MEI, LLC

3474 18th Avenue SE,  
Albany, OR 97322-7014,  
USA  
Tel: +1 541 917 3626  
Fax: +1 541 917 3623  
[www.marlerenterprises.net](http://www.marlerenterprises.net)

## 20 Facility consumables

### W.L. Gore & Associates

401 Airport Rd, Elkton,  
MD 21921-4236,  
USA  
Tel: +1 410 392 4440  
Fax: +1 410 506 8749  
[www.gore.com](http://www.gore.com)

## 21 Computer hardware & software

### Ansoft Corp

4 Station Square,  
Suite 200,  
Pittsburgh, PA 15219,  
USA  
Tel: +1 412 261 3200  
Fax: +1 412 471 9427  
[www.ansoft.com](http://www.ansoft.com)

### Crosslight Software Inc

121-3989 Henning Dr.,  
Burnaby, BC, V5C 6P8,  
Canada  
Tel: +1 604 320 1704  
Fax: +1 604 320 1734  
[www.crosslight.com](http://www.crosslight.com)

### Semiconductor Technology Research Inc

10404 Patterson Ave.,  
Suite 108, Richmond, VA 23238,  
USA  
Tel: +1 804 740 8314  
Fax: +1 804 740 3814  
[www.semitech.us](http://www.semitech.us)

## 22 Used equipment

### Class One Equipment Inc

5302 Snapfinger Woods Drive,  
Decatur, GA 30035,  
USA  
Tel: +1 770 808 8708  
Fax: +1 770 808 8308  
[www.ClassOneEquipment.com](http://www.ClassOneEquipment.com)

## 23 Services

### Henry Butcher International

Brownlow House, 50-51  
High Holborn, London WC1V 6EG,  
UK

Tel: +44 (0)20 7405 8411  
 Fax: +44 (0)20 7405 9772  
[www.henrybutcher.com](http://www.henrybutcher.com)

#### **M+W Zander Holding AG**

Lotterbergstrasse 30,  
 Stuttgart, Germany  
 Tel: +49 711 8804 1141  
 Fax: +49 711 8804 1950  
[www.mw-zander.com](http://www.mw-zander.com)

### **24 Consulting**

**Fishbone Consulting SARL**  
 8 Rue de la Grange aux Moines,

78460 Choisel,  
 France  
 Tel: + 33 (0)1 30 47 29 03  
 E-mail: jean-luc.ledys@neuf.fr

### **25 Resources**

#### **Al Shultz Advertising Marketing for Advanced Technology Companies**

1346 The Alameda,  
 7140 San Jose, CA 95126,  
 USA  
 Tel: +1 408 289 9555  
[www.alshultz.com](http://www.alshultz.com)

#### **SEMI Global Headquarters**

3081 Zanker Road,  
 San Jose,  
 CA 95134,  
 USA  
 Tel: +1 408 943 6900  
 Fax: +1 408 428 9600  
[www.semi.org](http://www.semi.org)

#### **Yole Développement**

45 rue Sainte Geneviève,  
 69006 Lyon,  
 France  
 Tel: +33 472 83 01 86  
[www.yole.fr](http://www.yole.fr)

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**3–7 March 2019**

## Optical Networking Communication Conference & Exhibition (OFC 2019)

San Diego Convention Center,  
San Diego, CA, USA

**E-mail:** [OFC@compusystems.com](mailto:OFC@compusystems.com)

[www.ofcconference.org](http://www.ofcconference.org)

**6–8 March 2019**

## BIT's 5th Annual World Congress of Smart Materials-2019

Rome, Italy

**E-mail:** [snowy@wscm-con.com](mailto:snowy@wscm-con.com)

[www.bitcongress.com/wscm2019](http://www.bitcongress.com/wscm2019)

**17–21 March 2019**

## APEC 2019: IEEE Applied Power Electronics Conference and Exposition

Anaheim Convention Center,  
Anaheim, CA, USA

**E-mail:** [apec@apec-conf.org](mailto:apec@apec-conf.org)

[www.apec-conf.org](http://www.apec-conf.org)

**17–20 March 2019**

## Optics Frontier – The 14th National Conference on Laser Technology and Optoelectronics (LTO 2019)

Novotel Atlantis Shanghai, China

**E-mail:** [LTO@siom.ac.cn](mailto:LTO@siom.ac.cn)

<http://lto2019.htcis.net>

**20–22 March 2019**

## LASER World of PHOTONICS CHINA 2019

Shanghai New International Expo Centre, China

**E-mail:** [info@world-of-photonics-china.com](mailto:info@world-of-photonics-china.com)

[www.world-of-photonics-china.com](http://www.world-of-photonics-china.com)

**20–22 March 2019**

## SEMICON China 2019

Shanghai New International Expo Centre, China

**E-mail:** [semichina@semi.org](mailto:semichina@semi.org)

[www.semiconchina.org](http://www.semiconchina.org)

**25–27 March 2019**

## CPV-15: 15th International Conference on Concentrator Photovoltaics)

Université Sidi Mohammed Ben Abdellah,  
Fes, Morocco

**E-mail:** [info@cpv-15.org](mailto:info@cpv-15.org)

[www.cpv-15.org](http://www.cpv-15.org)

**5 April 2019**

## 2nd ISELED conference

Conference Center Süddeutscher Verlag, Munich,  
Germany

[www.iseled-conference.com](http://www.iseled-conference.com)

**10–11 April 2019**

## Sensors Europe 2019

Estrel Convention Center, Berlin, Germany

**E-mail:** [events@IDTechEx.com](mailto:events@IDTechEx.com)

[www.idtechex.com/sensors-europe](http://www.idtechex.com/sensors-europe)

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**16–18 April 2019**

**23rd Annual Components for Military & Space Electronics Conference & Exhibition (CMSE)**

Four Points by Sheraton (LAX), Los Angeles, CA, USA

**E-mail:** info@tjgreenllc.com

[www.tjgreenllc.com/cmse](http://www.tjgreenllc.com/cmse)

**24–26 April 2019**

**International Workshop on Integrated Power Packaging (IWIPP 2019)**

Laplace-ENSEEIH, Toulouse, France

**E-mail:** iwipp2019@gmail.com

[www.iwipp.org](http://www.iwipp.org)

**29 April – 2 May 2019**

**2019 International Conference on Compound Semiconductor Manufacturing (CS MANTECH)**

Hyatt, Regency, Minneapolis, MN, USA

**E-mail:** chairman@csmantech.org

[www.csmantech.org](http://www.csmantech.org)

**7–9 May 2019**

**PCIM Europe (Power conversion and Intelligent Motion) 2019**

Nuremberg Messe, Germany

**E-mail:** daniela.kaeser@mesago.com

[www.mesago.de/en/PCIM/main.htm](http://www.mesago.de/en/PCIM/main.htm)

**15–17 May 2019**

**Intersolar Europe 2019**

Munich, Germany

**E-mail:** info@intersolar.de

[www.intersolar.de](http://www.intersolar.de)

**27–31 May 2019**

**ICPE 2019 – ECCE Asia: 10th International Conference on Power Electronics**

BEXCO, Busan, South Korea

**E-mail:** icpe2019@icpe2019.org

[www.icpe2019.org](http://www.icpe2019.org)

**24–27 June 2019**

**LASER World of PHOTONICS 2019**

Messe München, Germany

**E-mail:** info@world-of-photonics.com

[www.world-of-photonics.com](http://www.world-of-photonics.com)

**24–28 June 2019**

**PVSC 2019: IEEE 46th Photovoltaic Specialists Conference**

Chicago, IL, USA

**E-mail:** info@ieee-pvsc.org

[www.ieee-pvsc.org](http://www.ieee-pvsc.org)

**8–10 July 2019**

**2019 Summer Topicals Meeting Series**

Fort Lauderdale, FL, USA

**E-mail:** i.donnelly@ieee.org

[www.sum-ieee.org](http://www.sum-ieee.org)

**9–11 July 2019**

**SEMICON West 2019**

Moscone Center, San Francisco, California, USA

**E-mail:** semiconwest@xpressreg.net

[www.semiconwest.org](http://www.semiconwest.org)

**10–11 July 2019**

**UK Semiconductors 2019 (UKS'19)**

University of Sheffield, UK

**E-mail:** edmund.clarke@sheffield.ac.uk

[www.uksemiconductors.com](http://www.uksemiconductors.com)

**21–24 July 2019**

**AVS 19th International Conference on Atomic Layer Deposition (ALD 2019), featuring the 6th International Atomic Layer Etching Workshop (ALE 2019)**

Bellevue, Washington, USA

**E-mail:** della@avs.org

[www.ald2019.avs.org](http://www.ald2019.avs.org)

**11–15 August 2019**

**SPIE Optics + Photonics 2019**

San Diego Convention Center, San Diego, California, USA

**E-mail:** customerservice@spie.org

[http://spie.org/Optics\\_Photonics](http://spie.org/Optics_Photonics)

**2–5 September 2019**

**21st Conference on Power Electronics and Applications (and Exhibition), EPE'19 ECCE (Energy Conversion Congress & Expo) Europe**

Genova, Italy

**E-mail:** info@epe2019.com

[www.epe2019.com](http://www.epe2019.com)

**4–7 September 2019**

**CIOE 2019: 21st China International Optoelectronic Exposition**

Shenzhen Convention & Exhibition Center, China

**E-mail:** cioe@cioe.cn

[www.cioe.cn/en](http://www.cioe.cn/en)

**18–20 September 2019**

**SEMICON Taiwan 2019**

Taipei Nangang Exhibition Centre, Taiwan

**E-mail:** semicontaiwan@semi.org

[www.semicontaiwan.org](http://www.semicontaiwan.org)



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